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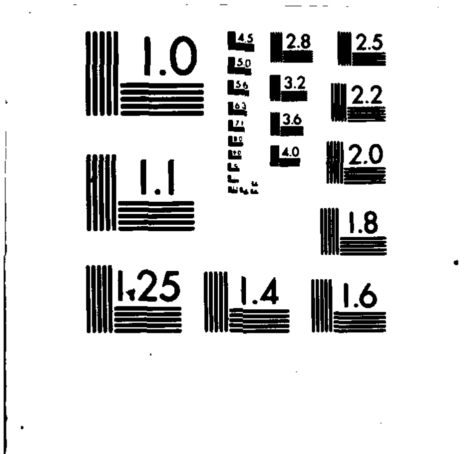

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TRUNK FLUTTER ANALYSIS PROGRAM USER'S MANUAL

FOSTER-MILLER ASSOCIATES, INC.
350 SECOND AVENUE
WALTHAM, MA 02154

NOVEMBER 1979

TECHNICAL REPORT AFFDL-TR-79-3121
USER'S MANUAL
Final Report for period May 1978 — July 1979

Approved for public release; distribution unlimited.

AIR FORCE FLIGHT DYNAMICS LABORATORY
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This technical report has been reviewed and is approved for publication.

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This User's Manual (Computer Program) describes the computer programs for trunk flutter analysis. It includes descriptions, user instructions, and a sample run for the trunk flutter dynamic simulation program, and an eigenvalue calculation program for a linearized static trunk model. The results of the study under which this User's Manual was prepared are contained in AFFDL-TR-79-3102, "Analysis of Trunk Flutter in an Air Cushion System, dated August 1979.

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FOREWORD

The work in this document was performed under Contract No. F33615-78-C-3412, Work Unit No. 2307N204, "Trunk Flutter Analysis". The technical project officer of the project was Dr. Ben J. Brookman, Jr. The final report of the above contract is contained in AFFDL-TR-79-3102.

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1. INTRODUCTION

This report describes a computer program developed as part of the contract F33615-78-C-3412, Trunk Flutter Analysis. The computer program simulates behavior of a two-dimensional trunk segment in presence of air flows existing in an air cushion landing system (ACLS). Through such simulations a greater understanding of trunk flutter mechanisms can be achieved and ways to eliminate flutter in future designs can be developed.

The trunk-fluid flow system addressed by the program is shown in Figure 1.* As shown in the figure the trunk is assumed to be fed by a fan with the user selected characteristics. The air supplied to the trunk by the fan flows out at two places.

a. Through the trim valves to the cushion
b. Through orifices at the side and the bottom of the trunk.

The cushion air flows to the atmosphere from the bottom of the trunk.

The trunk, assumed to be made of an elastic membrane with a finite mass and flexural rigidity is divided into a number of mass nodes, each connected to the other by springs as shown in Figure 2.

The separation point is assumed to be always at a particular slope of the trunk. However, in view of the additional work that needs to be done in identifying the location of the separation point, the computer program provides various options in defining the separation point location.

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* See Final Report "Contract No." F33615-78-C-3412 for details of the model.

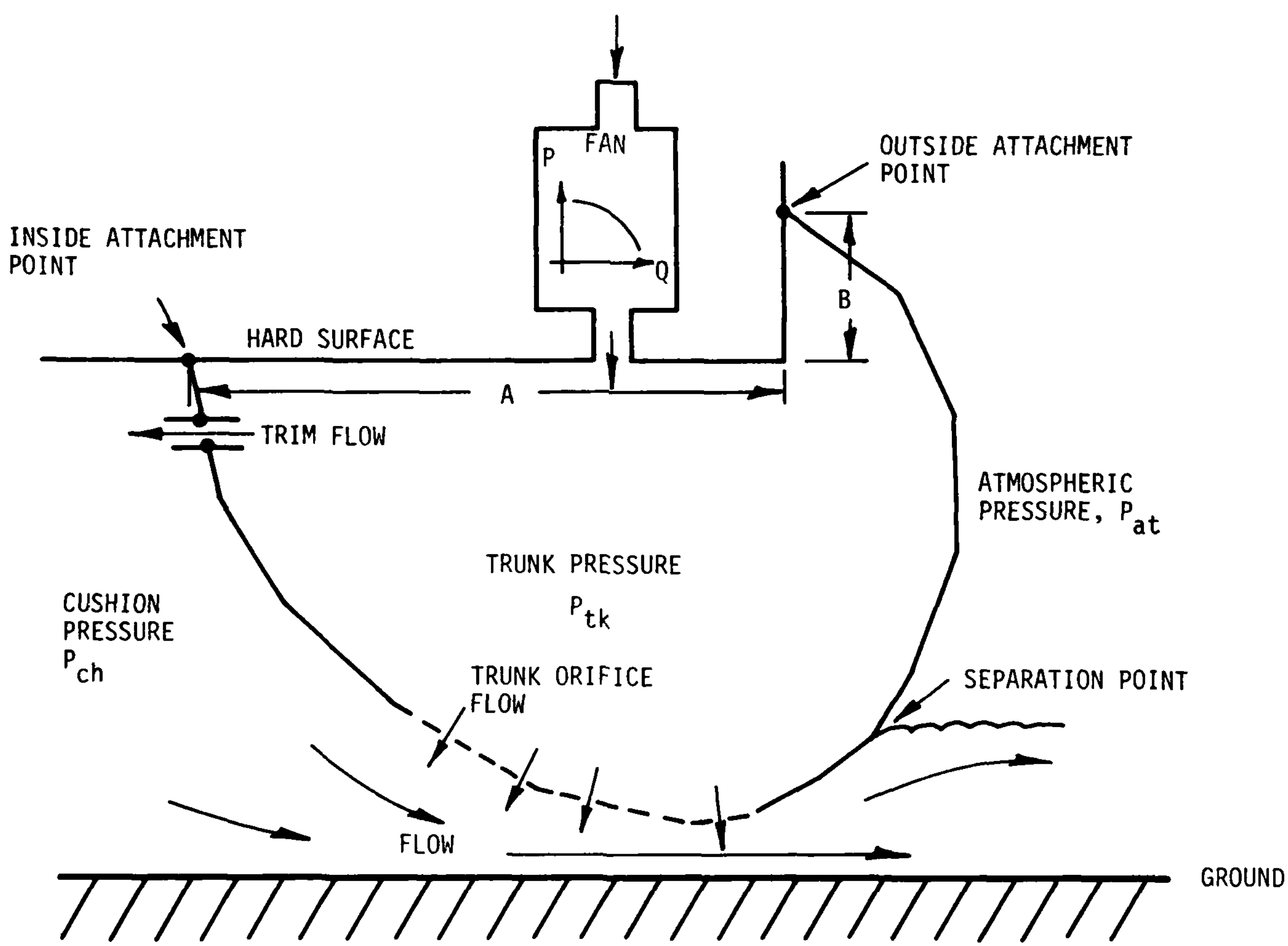


Figure 1. ACLS trunk flow model.

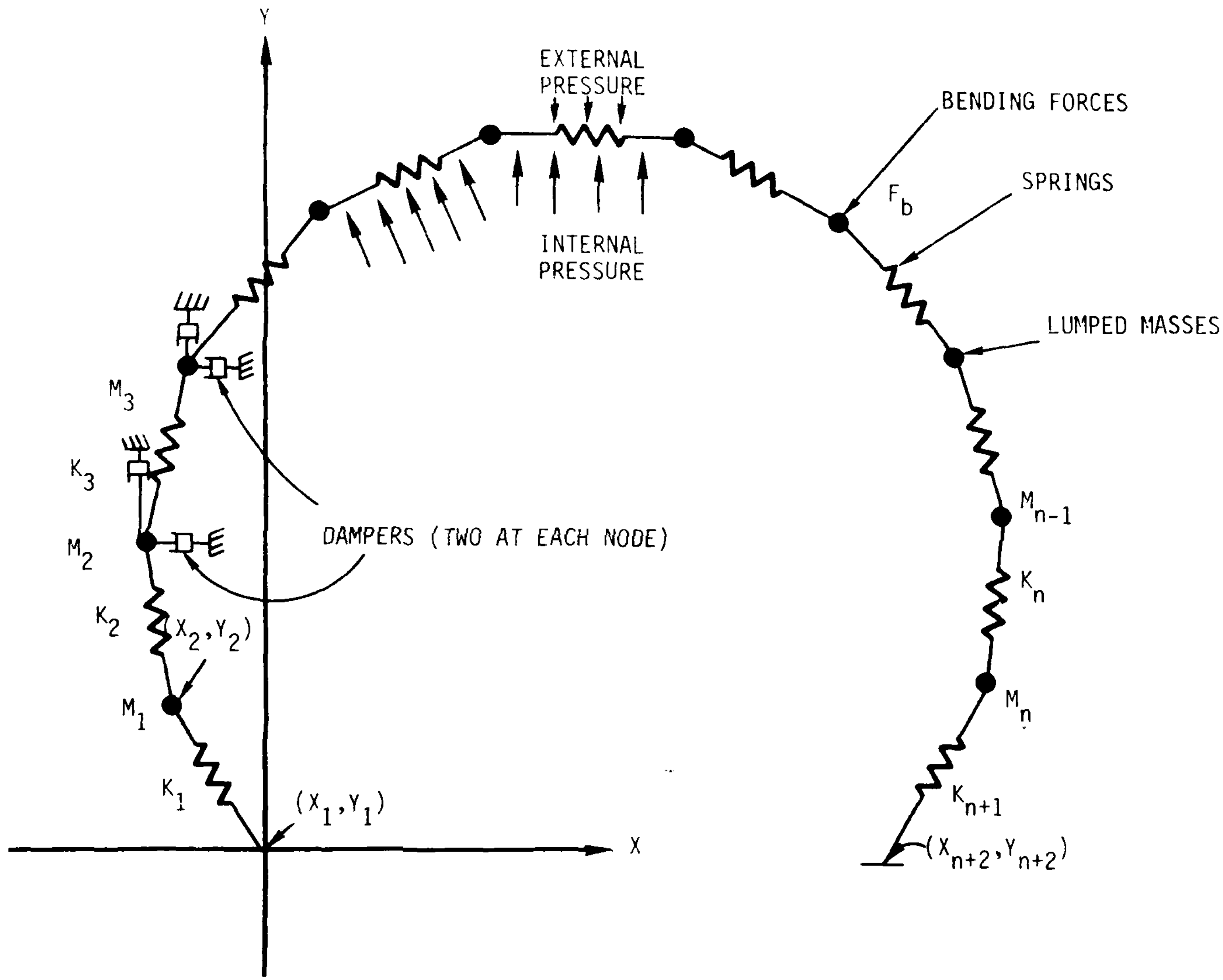


Figure 2. Trunk representation for the flutter models.

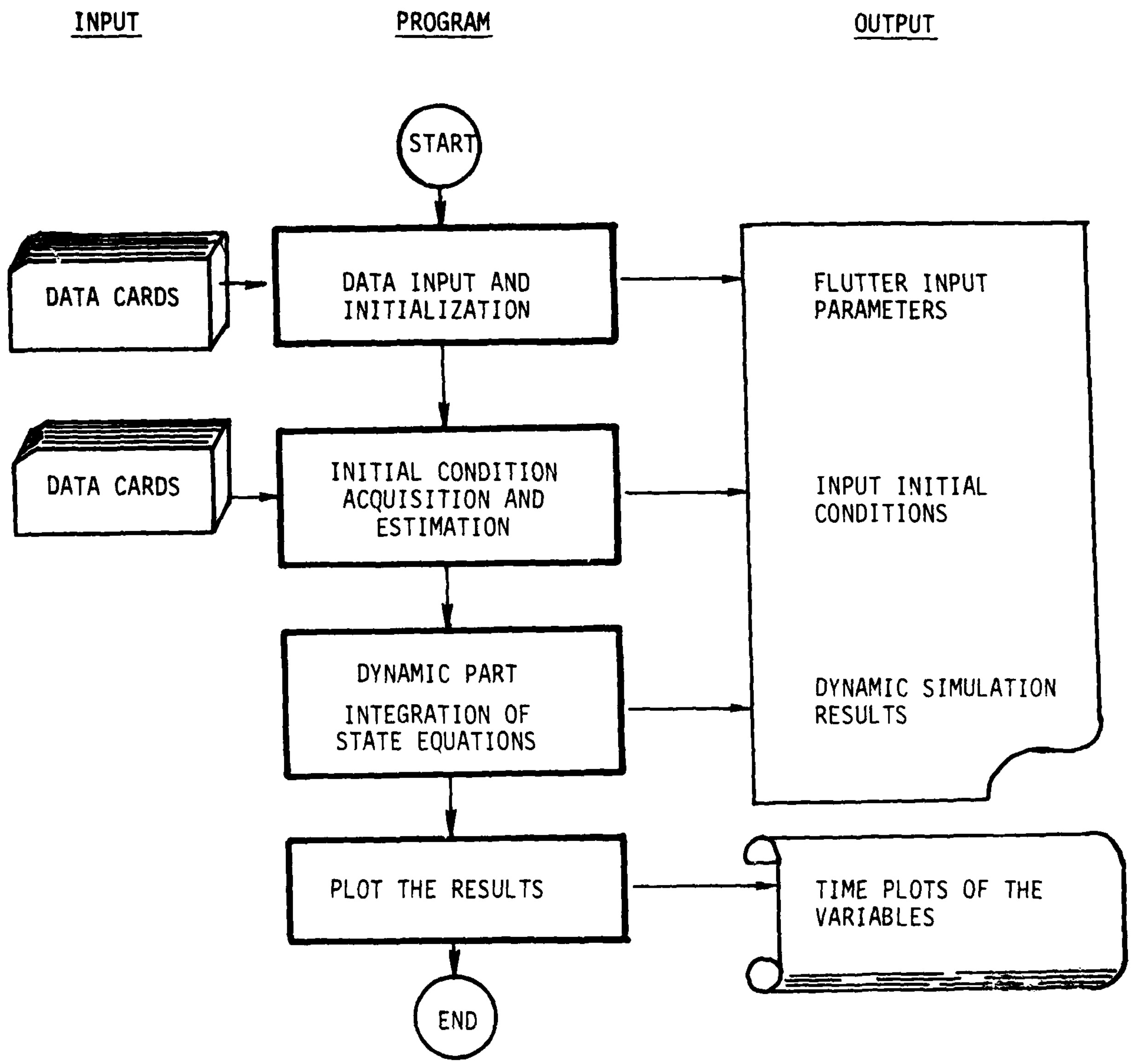


Figure 3. Program structure.

For this configuration of the trunk-airflow interaction the computer program simulates the trunk behavior for a variety of fluid flow and trunk parameters. A typical output of the simulation consists of the shape of the trunk defined by the location of the nodes as a function of time. In addition, the fluid parameters, such as the cushion and the trunk pressures, and various flows are also available in the output.

The computer program is designed to be flexible and versatile so that the trunk behavior can be studied for variations in a number of parameters. This way the program can be of assistance in developing flutter free configurations. A list of major parameters that can be varied is shown in Table 1. In order to ensure that the user can employ this flexibility easily, the program is organized in such a manner that:

a. The major parameters are varied just through data input

b. Any changes in the program made necessary due to additional experimental information on flutter characteristics could easily be performed.

The modular structure of the program which makes such changes easy to accomplish is described in Section 2 of the report. The instructions for using the program are in Section 3 whereas Section 4 illustrates the program capability through an example. Appendix A summarizes the equations incorporated in the program. These equations are based on the model described in the final report.*

---

*See Final Report of Contract No. F33615-78-C-3412 for details.

TABLE 1. THE CAPABILITIES OF THE TRUNK FLUTTER SIMULATION PROGRAM

The program simulates the trunk behavior for variations in the following parameters.

ACLS Parameters

- **Trunk Parameters**
  - attachment points
  - cross section length
  - elasticity variations along the length
  - flexural stiffness variations along the length
  - density variations along the length
  - trim valve size
  - trunk orifice size and location
- **Fluid Parameters**
  - fan characteristics
  - cushion volume
  - trunk volume
  - separation point
  - global damping
- **Operation Parameters**
  - hard surface clearance
- **Flutter Suppression Parameters**
  - strake at any location
  - minimum gap area
  - external spring at any location

Program Parameters

- **Simulation Parameters**
  - time step
  - time limit
  - plotting options
- **Trunk Model Parameters**
  - number of nodes
- **Options**
  - separation point options*
    - a. diffuser model, i.e. separation at a fixed slope
    - b. fixed gap to separation point height
    - c. trunk orifice flow induced separation i.e., separation occurs at the last orifice row if it is at a slope less than the diffuser model slope
  - cushion - trunk pressures options
    - a. fixed cushion and trunk pressures**
    - b. variable cushion pressure fixed trunk pressure**
    - c. variable cushion and trunk pressures with fan characteristics
  - pressure profile on trunk bottom options
    - a. nonvariable pressure profile**
    - b. variable pressure profile without trunk orifice flow**
    - c. variable pressure profile with trunk orifice flow

* For flutter studies conducted before further investigations in the separation point location are performed

** Used for initial studies on the behavior of a particular trunk design

Appendix B describes a program, which was also developed as a part of this contract, to calculate the eigenvalues of a linearized trunk model. This program can enhance the understanding of the dynamics of the trunk motion through prediction of the natural frequencies and the mode shape.

Appendix C summarizes Principal Program Nomenclature, and Appendix D has the listings of the computer programs.

2. PROGRAM ORGANIZATION

Overall structure of the computer program developed for simulating the dynamic behavior of the trunk of air cushion landing system (ACLS) is described in this section. Details of the eigenvalue computer program are, however, described in Appendix B.

The computer program has a modular structure, that is, there is a main program which coordinates operations of a number of subroutines, each of which perform a specific function. Such a structure makes the program efficient and easy to modify. As shown in Figure 3, there are four steps in the program execution:

a. Data input and initialization
b. Initial condition acquisition and estimation
c. Dynamic part execution
d. Plotting the results.

Details of each of these steps are described in the following subsection.

2.1 Program Execution Steps

The manner in which the main program executes each of the above four steps is shown in Figure 4. The main program, DYSYS, controls the dynamic simulation of the trunk model. DYSYS coordinates integration of the differential equations, printing of the state variables, and plotting the results. It initially calls subroutine EQSIM to initialize values of the derivatives of the state variables. DYSYS prints out the initial conditions and then enters the integration loop which calls subroutine RKDIF. DYSYS calls RKDIF at every time step until the time

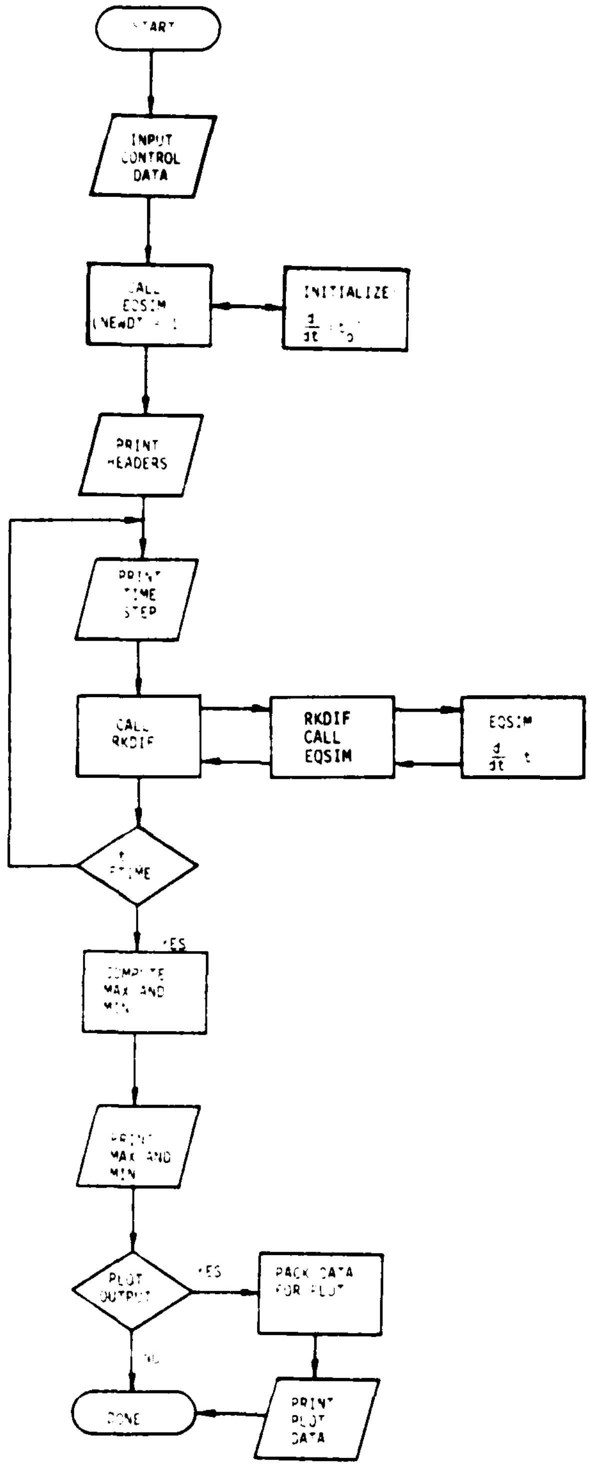


Figure 4. Simulation flowchart.

limit of the simulation is reached. RKDIF is the integration subroutine which incorporates a fourth order Runge-Kutta scheme. The integration scheme requires updating the differential values of the variables four times every time step, therefore, subroutine EQSIM is called four times by subroutine RKDIF.

RKDIF is the numerical integration subroutine which calculates the values of the state variables at time t + dt, given the values at time t, using a fourth order Runge-Kutta method. The integration scheme is summarized below:

a. The iteration procedure starts with the values of the state variables y_1, y_2 etc., at time t.

$$Y_i(t), \ I = 1,n$$

b. The slopes $Dy_i(t)$ are then determined from $y_i(t)$ by calling EQSIM

$$Dy_i(t) = dy_i(t)/dt$$

c. The values y_{i1} at time t + dt/2 are then determined,

$$y_{i1} = y_i + Dy_i \cdot dt/2$$

d. The slopes Dy_{i1} (t + dt/2) are then determined by calling EQSIM and using the values of y_{i1} found in c.

e. The values y_{i2} at time $t + dt/2$ are then determined

$$y_{i2} = y_i + Dy_{i1} \cdot dt/2$$

f. The slopes Dy_{i2} $(t + dt/2)$ are then determined from EQSIM using the values of y_{i2} found in e. above.

g. The values y_{i3} at time $t + dt$ are then determined,

$$y_{i3} = y_i + Dy_{i2} \cdot dt$$

h. The slopes Dy_{i3} at time $t + dt$ are then determined from EQSIM using the values of y_{i3} found in g. above.

i. Finally, the values of the state variables at time $t + dt$ are found as follows:

$$y_i(t + dt) = y_i(t) + (Dy_i + 2Dy_{i1} + 2Dy_{i2} + Dy_{i3})\, dt/6$$

During each integration step (that is, to advance from t to t + dt), EQSIM is called four times to determine the slopes (b, d, f, and h above).

Subroutine EQSIM, which calculates the various flows, pressures, motions, and forces, is the only model specific

subroutine in the simulator program and has all the parameters, variable initialization input and system equations contained in it. This subroutine calls subroutine TRUNK in order to calculate the initial trunk shape for the given trunk length and attachment points.

Once the simulation is completed the main program calls subroutines PLOTTER, PACKER, PRNTPT and PSTORE in order to produce time history plots of any of the system state variables on a printer plot. Table 2 summarizes the subroutines used in the program.

TABLE 2. A SUMMARY OF SUBROUTINES

No.	Subroutine	Primary Function	Group
1	DYSYS*	Main program; control integration of state equations and I/O	Main*
2	EQSIM	Compute state derivatives and system pressure-flow-geometry	Dynamic
3	RKDIF	Coordinates Runge-Kutta integration algorithm	Dynamic
4	PLOTTER	Controls data plotting	Plot
5	PACKER	Read plot data from simulation output file	Plot
6	PRNTPT	Plot data on printer	Plot
7	PSTORE	Write simulation output file	Plot
8	TRUNK	Compute TRUNK shape	Geometry

*DYSYS is the main calling program.

3. PROGRAM USER INSTRUCTIONS

3.1 Program Input Data

The required program input data are supplied to the program in three ways:

a. By data cards for parameters and design variables which are frequently changed.

b. By data specifications included within the program, for example, physical constants.

c. Through subroutine TRUNK which can be used to compute a trunk shape.

3.1.1 Input Data Format

The input data set format specification is designed to allow flexibility in the program parameter initialization and option specification. Program variables are input in a specified format and sequence using FORTRAN formatted I/O. Some input variables are not required for certain operating conditions. These special cases are noted in the input description (marked with an * after the card number). Variables which are vectors are read sequentially under their format specification, as noted by the index after the variable name. Special notes on some variables are included in subsection 3.1.3 where further explanation of the variable is required. The format used in the following input card description is:

CARD NO., NAME, VECTOR INDEX, FORMAT, DESCRIPTION.

1. FTIME, DTIME, STIME (I2, 8X, 2G10.5)

FTIME - Final time of simulation
DTIME - Time step for simulation
STIME - Starting time for simulation (see note 1)

2. IPRNT(I); I = 1, 9 (9I2)

IPRNT - Print control vector, print state variable IPRNT(I) every time step.

3. NPLTM (I2)

NPLTM - Plot control flag, NPLTM = number of plots to be made.

4. XLAB(I); I = 1, 40 (40A2)

Lable card for simulation output

5. ICNTL(I); I = 1, 16 (16I1)

ICNTL(I) = Execution option selection

ICNTL(1) = 1 for dynamic cushion pressure
ICNTL(2) = 1 for dynamic trunk pressure and fan characteristics
ICNTL(3) = 1 for trunk orifice flow
ICNTL(4) = 1 for separation point interpolation
ICNTL(5) = 1 for static trunk shape
ICNTL(6) = 1 for nonvariable pressure profile (see card 25)

ICNTL(1) to ICNTL(3) have to be 1 for complete simulation

6. NODES, ICFLAG, IFXN, IFSEP, ILENG, INSEP (10I5)

NODES - Number of trunk nodes

ICFLAG - Trunk shape initial condition; 1 = compute,
0 = read initial condition in terms of X, Y
(see card No. 12, 13)

IFXN - Number of steps tc be skipped in printout

IFSEP - Separation point model option
= 1 for fixed gap to separation point height
= 2 for diffuser model
= 3 for separation point fixed at node number "INSEP"

ILENG - Initial length of segments option
= 0 compute length of node-node segments
= 1 read data cards for the initial length (see card No. 11)

INSEP - Separation point node (IF IFSEP = 3)

7. A, B, L, HYI (8G10.5)

A - Horizontal separation between the attachment points.

B - Vertical separation between the attachment points.

L - Trunk membrane length, between the attachment points.

HYI - Initial trunk height.

8. SSLENG, TPERIM (8G10.5)

SSLENG - Length of trunk with significant gap area for flow to atmosphere from cushion

TPERIM - Perimeter of trunk, around complete ACLS

9. ATC, ATRIM (8G1.0.5)

ATC - Area of trunk to cushion flow, not including trim valve (ATRIM) (ATC not used if option 3 used)

ATRIM - Area of trim valve for fixed flow area to cushion

10. ATCF(I); I = 1, nodes + 1 (8G10.5)

ATCF - Flow area of trunk orifice per unit width for node to node link
(assume uniform density for each link)

11. *RLENGO(I); I = 1, nodes + 1 (8G10.5)

RLENGO - Element lengths at zero extension; needed if ILENG = 1 (see card No. 6)

12. *X(I); I = 2, nodes + L (8G10.5)

X Node position values; needed if ICFLAG = 0 (see card No. 6)

13. *Y(I); I = 2, nodes + 1 (8G10.5)

Y Node position values; needed if ICFLAG = 0 (see card No. 6)

14. RMASS(I); I = 1, nodes (8G10.5)

RMASS - Nodal mass values

15. RKVEC(I); I = 1, nodes (8G10.5)

RKVEC - Trunk elasticity of membrane links between nodes

16. RBVEC(I); I = 1, nodes (8G10.5)

RBVEC - Flexural stiffness per node

17. DAMP(I); I = 1, nodes (8G10.5)

DAMP - Nodal damping ratio (see note 2)

18. TREST, DAMPR (8G10.5)

TREST - Simulation time damping ratio change

DAMPR - Damping ratio change multiplication factor (see note 3)

19. IEXT, RKEXTX, RKEXTY (I2, 2G10.5)

IEXT - Node of external spring attachment

RKEXTX - X direction spring constant

RKEXTY - Y direction spring constant (see note 4)

20. AIFAN, TKVOL, VCH (8G10.5)

AIFAN - Inertance of air in the fan (see note 5)

TKVOL - Trunk volume

VCH - Cushion volume

21. CQ0, CQ1, CQ2, CQ3, CQ4 (8G10.5)

CQ0 - Fan polynomial coefficient (see Figure 5)

CQ1 - Fan polynomial coefficient

CQ2 - Fan polynomial coefficient

CQ3 - Fan polynomial coefficient

CQ4 - Fan polynomial coefficient (see note 7)

22. CTC, CTRIM, CGAP, TSEP (8G10.5)

CTC - Discharge coefficient for the trunk orifices

CTRIM - Discharge coefficient for the trim valve

CGAP - Discharge coefficient for the gap

TSEP - Separation angle (in radians)

23. YGRNDS, SRATIO, YDMIN (8G10.5)

YGRNDS - Hard surface clearance

SRATIO - Constant gap to separation point height ratio

YDMIN - Maximum allowable trunk height for the minimum gap area method of flutter suppression. (strip or puck induced minimum gap area)

24. PTK, PCH, QGAP (8G10.5)

PTK - Trunk pressure initial condition (or constant)

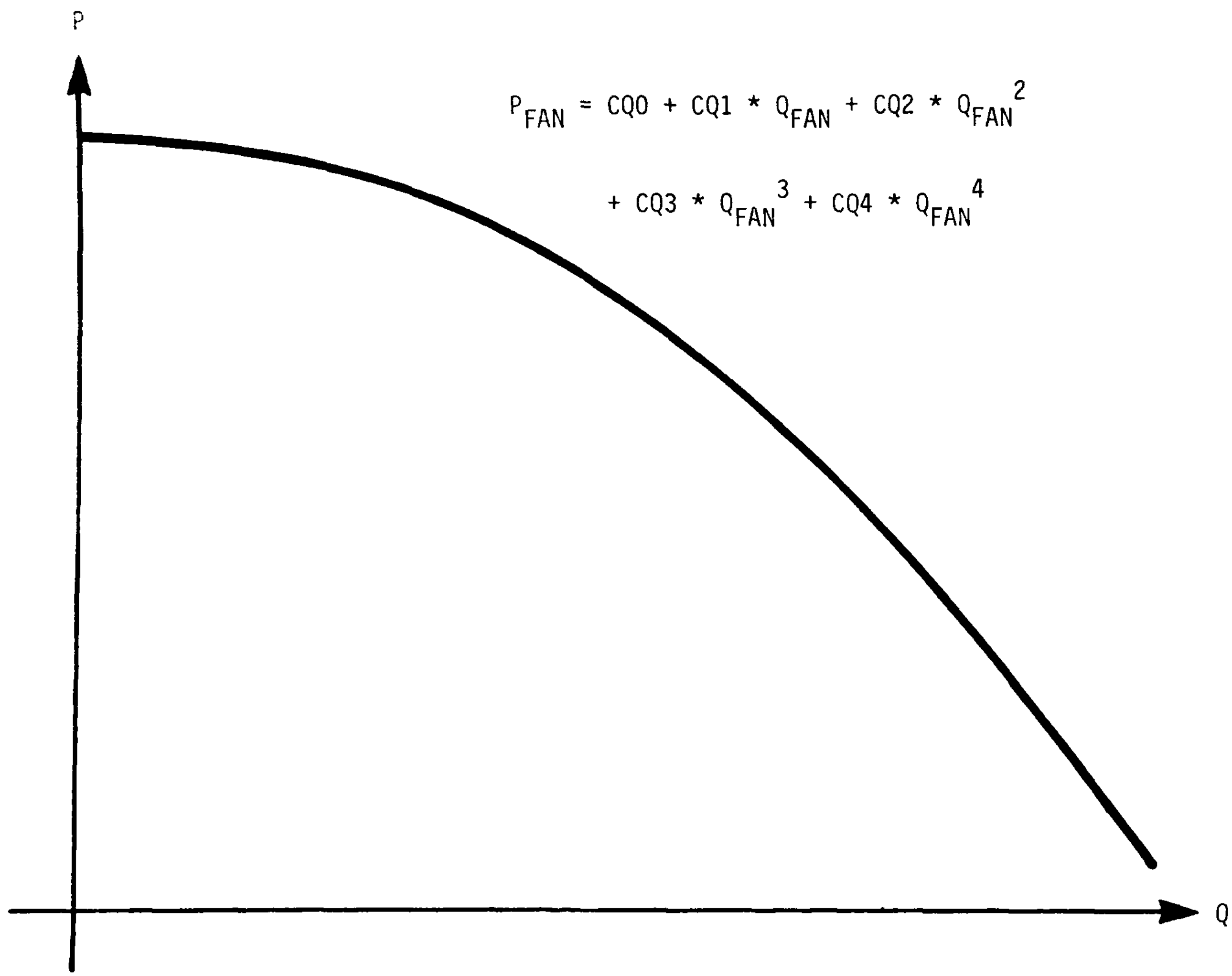


Figure 5. Fan pressure versus flow polynomial.

PCH - Cushion pressure initial condition (or constant)

QGAP - Exit flow, initial condition (not required unless ICNTL(1) and ICNTL(2) are 1)

25.* PEXT(I); I = 1, nodes (8G10.5)

PEXT - External pressure at nodes, used for initial shape computation (ICNTL(6) has to be = 1)

26.* NVPLOT, NPLT(I), I = 1,5 (I1, 4X, 5I2)

NVPLOT - Number of variables on plot

NPLT - Variable to be plotted (state variable number to be plotted = NPLT(I) * 2 + 4, see note 6) (see note below and note 6)

27.* TPLSRT, TPLSTP, DTPLOT, XMIN, XMAX (6F12.5)

TPLSRT - Plot start time

TPLSTP - Plot end time

DTPLOT - Time increment between plot points

XMIN - Minimum value of plot axis (optional)

XMAX - Maximum value of plot axis (optional)

If XMIN = XMAX = 0.0, plots will be autoscaled by program. (See note below)

*Note: Cards 26 and 27 are input only if NPLTM > 0

3.1.2 Internal Data

Internal constants used in the program include:

CKK - Polytropic expansion exponent, k, 1.4

G - Gravitational acceleration, g, 32.174 ft/sec^2

PI - π, 3.1415926535

PAT - Atmospheric pressure (absolute), Pat, 2116.8 lb/ft^2

RHO - Air density, ρ, 0.00234151 slugs/ft^3

3.1.3 Special Notes on Input Data

Note 1 - Time step for simulation has to be judiciously chosen by the user. Using too large a time step will cause numerical instability, using too small a time step will make the simulation uneconomical and inaccurate. In fact, the time step should be "small" compared to the smallest period of system vibration.

For the simulation results described in this manual, a time step of 0.001 sec was used. This may serve as a good starting point for initial calibration simulations for a different ACLS system. If the variables, particularly the higher frequency variables, such as the node displacements (X, Y) show a rapidly fluctuating characteristic, the time step should be reduced until such tendencies disappear. On the other hand, the time step may be increased if the time step of 0.001 sec is much smaller than the time step at which the fluctuations appear.

Note 2 - The global damping values (ratios) specified on input must be chosen by making an engineering estimate of the energy dissipated by trunk motion. Actual extension and bending motion damping values have been approximated by a global (X, Y) velocity damping force.

Note 3 - TREST, DAMPR - TREST is the simulation time that the program can change the global damping ratio values DAMP(I) that were given at input. At time TREST the values of DAMP(I) are multiplied by the constant DAMPR. This option allows the initial shape of the trunk and fluid flow variables to be computed for a highly damped system to get the required initial conditions and then to simulate the lightly damped system from time equals TREST onward.

Note 4 - IEXT, RKEXTX, RKEXTY - This option allows the attachment of a spring from node number IEXT to the ACLS frame. The X and Y direction stiffnesses are input as RKEXTX and RKEXTY. The initial trunk shape is assumed at the zero extension position.

Note 5 - Fan air inertance is inertance of the air residing in the fan at any instant. A good estimate of the inertance is obtained by:

$$I_f = \frac{\rho \ell}{A} = \text{AIFAN}$$

where

I_f = air inertance

ℓ = average flow path length in the fan, which may be approximated as the length of the fan

ρ = average air density

A = Cross section area of flow.

Note 6 - The state variables for the simulation are stored in a vector. Each node requires four state variables for integration:

I = (J + 1) * 4 + 1 for node No. J

STATE(I) = X Velocity of node (J)

STATE(I + 1) = X Displacement of node (J)

STATE(I + 2) = Y Velocity of node (J)

STATE(I + 3) = Y Position of node (J)

If optional dynamic trunk or cushion pressure are used these variables are appended at the node state vector:

I = (NODES + 2) * 4 + ICNTL(1) + ICNTL(2) * 2

STATE(I) = Dynamic cushion pressure

STATE(I - 1) = Dynamic trunk pressure

STATE(I - 2) = Dynamic fan flow

STATE(I + 1) = Trunk membrane length

STATE(I + 2) = Flow, trunk to cushion

STATE(I + 3) = Flow, trim

STATE(I + 4) = Flow, cushion to atmosphere

STATE(I + 5) = Average cushion pressure P(t)

STATE(I + 6) = Flow, cushion and trunk orifices to atmosphere

STATE(I + 7) = Flow, trunk to atmosphere.

Note 7 - CQ0, CQ1, CQ2, CQ3, CQ4 - These fan flow variables are coefficients for a fourth order polynomial. They are found by doing a linear polynomial regression on the fan data using a standard regression program. (See IBM-SSP manual.)

Note 8 - SRATIO - This ratio is an optional flow separation calculation technique which bases the height of the separation point gap as a ratio of minimum gap to separation gap equal to SRATIO.

The last seven variables are not state variables but auxiliary storage variables.

3.1.4 Program Option Operation

The dynamic flutter simulation program includes a number of model options which allow the user to simulate a variety of ACLS designs and to study a number of system features. The simulation options include:

STATIC PRESSURE LOAD PROFILE
FLOW INDUCED, DYNAMIC, PRESSURE PROFILE
VARIOUS FLOW SEPARATION POINT MODELS
EXTERNAL SPRING ATTACHMENT
DAMPING RATIO STEP CHANGE VERSUS TIME
TRUNK SHAPE INPUT OR CALCULATION

FLOW DYNAMICS INTEGRATION WITH STATIC TRUNK SHAPE
VARIOUS PRESSURE DYNAMIC MODELS

These features allow a number of types and phases of analysis to be performed with the program. A description of the options and how to select them is presented here.

Program options:

1. Static pressure load profile.

ICNTL(6) = 1
PEXT(I) = Node pressure (external) values. (Optional input)

This option is useful for measuring pressurized trunk shapes without pressure load dynamics on trunk surface, (for example: out-of-ground-effect).

2. Flow induced dynamic pressure profile.

ICNTL(6) = 0 (DEFAULT MODEL)

This option uses a Bernoulli flow equation for flow from the cushion area to atmosphere. This is the normal default flow model. When trunk flow orifices are included a modification to the flow equations is required:

ICNTL(3) = 1

This results in an interactive flow computation which includes cushion exit flow and trunk orifice flow which combine and flow to atmosphere.

3. Flow separation point models.

Several models exist for the flow separation point calculation.

a. Diffuser model.

IFSEP = 2

This model uses a diffuser slope value of TSEP radians to set the separation point at the node where the trunk surface slope is closest to TSEP. Typical values are in the range of 6 to 12 degrees.

b. Fixed gap ratio.

IFSEP = 1

This model sets the separation point at the node point where the gap height is closest to the ratio of minimum gap height divided by the ratio, SRATIO. (See note 8.)

c. Fixed separation node.

IFSEP = 3
INSEP = separation node number

This option allows the user to set the separation point at the specific node. This feature is useful for simulating strakes or other flow separation inducing devices.

d. Trunk orifice flow induced separation.

ICNTL(3) = 1

IFSEP = 2

For the diffuser model a special case can exist when the trunk flow orifices are utilized. If separation would occur after the trunk orifice area it will actually occur at the last trunk orifice row.

4. External spring attachment.

IEXT = node #
RKEXTX = X direction spring stiffness (linear constant value)
RKEXTY = Y direction spring stiffness (linear constant value)

This option is used to simulate the attachment of an external spring to the trunk membrane from the ACLS frame. If IEXT = 0 the option is overridden.

5. Damping ratio step change versus time.

TREST = time of damping change
DAMPR = damper ratio multiplication factor

This option allows the global damping ratio of the trunk nodes, DAMP(I), to be changed during the simulation. This feature can be used to integrate the trunk equations in an overly damped manner to reach an equilibrium value or to compute quasi-static trunk dynamics. When the initial conditions of the system are not well known the initial computation with a high damping ratio will allow them to stabilize before simulating a flutter situation.

6. Trunk shape selection.

ICFLAG = 0 Input node x, y values
= 1 Compute node x, y values

ICFLAG = 0 Input node x, y values
= 1 Compute node x, y values

The TRUNK subroutine can only calculate the positions of equi-spaced trunk nodes. The user inputted trunk node x, y values are the most useful and flexible because it allows variable node placement and spacing. RLENGO is also controlled in a similar manner.

ILENG = 0 Compute lengths
      = 1 Input lengths

The computed lengths are only good for equi-spaced nodes and user input is the recommended system.

7. Flow dynamics with static trunk profile.

ICNTL(5) = 1

This option allows flow and pressure data to be computed dynamically, but for the trunk shape to be held fixed. This feature is useful for checking out flow dynamics with a controlled static trunk system.

8. Various pressure dynamic models.

Three different fluid system models are included in the program:

ICNTL(1), ICNTL(2)

a. The pressures can be fixed to the input values.

   ICNTL(1) = ICNTL(2) = 0

b. The cushion pressure can be a dynamic function of the flows and orifice areas in the ACLS system.

   ICNTL(1) = 1, ICNTL(2) = 0

c. The cushion and trunk pressures and fan flow are dynamic functions of the fan dynamics, orifice areas, and exit flows. If the dynamic trunk and fan option is used, the dynamic cushion pressure must be used also.

   ICNTL(1) = ICNTL(2) = 1

3.2 Program Output

The printout includes the following data:

a. Input Parameters - Trunk parameters, fan parameters, control parameters, simulation parameters, flow path parameters, structural parameters are printed out after input. The options activated by the ICNTL vector are printed out to indicate the features of the model being simulated.

b. Dynamic Simulation Data - During the dynamic simulation the trunk shape, pressures and flow values, and other requested data are printed out every IFXN time steps.

c. Time Response Plots - After the simulation reaches its final time the program can produce a printer plot of any of the dynamic variables such as trunk node position, dynamic pressures, or flow etc.

Listing of output data in sequential order.

1. Integration start time, STIME; integration final time, FTIME; integration time step, TSTEP.

2. System state variables, to be printed (see card No. 2).

3. Simulation label, XLAB(I).

4. Control vector, ICNTL(I).

5. Options in effect for simulation,

   a. Dynamic cushion pressure
   b. Dynamic trunk-fan pressure
   c. Trunk orifice flow

d. Separation point interpolation

e. No trunk motion test

f. Pressure profile.

6. Number of nodes, NODES; number of system state variables, NSTATE; X, Y node point selection option ICFLAG; print out skip number IFXN; separation point selection model, IFSEP; separation point, INSEP; element length option, ILENG.

7. Horizontal attachment separation, A; vertical attachment separation, B; trunk length, L; trunk height, HYI.

8. Trunk gap exit flow length, SSLENG; trunk perimeter, TPERIM.

9. Trunk to cushion flow area, ATC; trim valve area ATRIM.

10. Trunk orifice element flow areas, ATCF(I).

11. Trunk element zero extension length, RLENGO(I) (option).

12. X node position values, X(I).

13. Y node position values, Y(I).

14. Trunk nodal masses, RMASS(I).

15. Trunk elastic stiffness, RKVEC(I).

16. Trunk bending stiffness, RBVEC(I).

17. Nodal damping ratios, DAMP(I).

18. Damping reset time, TREST, reset factor DAMPR.

19. External spring attachment node, IEXT; X direction spring constant, RKEXTX; Y direction spring constant, RKEXTY.

20. Fan air inertance, AIFAN; trunk volume TKVOL; cushion volume VCH.

21. Fan polynomial coefficients, CQ0, CQ1, CQ2, CQ3, CQ4.

22. Trunk to cushion flow discharge coefficient, CTC; trim valve flow discharge coefficient, CTRIM; cushion flow area discharge coefficient, CGAP; separation angle, TSEP.

23. Hard surface clearance, YGRNDS; gap to separation point height ratio, SRATIO; maximum allowable trunk height, YDMIN.

24. Trunk pressure initial condition or constant, PTK; cushion pressure initial condition or constant, PCH; exit flow (fan) initial condition, QFAN.

25. External pressure profile, PEXT(I) (option).

NOTE

Outputs 26 to 30 are printed every IFXN time steps.

26. Simulation time, TIME.

27. Dynamic cushion pressure, STATE(N); trunk length, STATE(N+1); trunk to cushion flow, QTC; trim flow, QTRIM; cushion to atmosphere flow, QCA. (option, ICNTL(1) = 1.)

28. Y node values, Y(I).

29. Cushion separation node, ICS; exit separation node, ISEP; lowest node, INODE, separation point area, YASEP; minimum gap area, YGAPM; gap area at separation node, AGAP(ISEP); exit flow velocity, VEXIT; exit flow, QEXIT; cushion pressure, PCH; trunk pressure, PTK; fan flow, QFAN.

30. External pressure at nodes, PEXT(I).

NOTE

Outputs 31 and 32 are for plot outputs.

31. Plot curve state variable numbers, IDUM(I).

32. Print plot output (see sample output).

33. State variable maximum and minimum values, YMAX(I); YMIN(I); (option, if any IPRNT(I) $\neq$ 0).

4. ILLUSTRATIVE SIMULATION

The following describes the input data and the output printout and print plot for a flutter simulation of a typical ACLS. The typical case simulated includes the effects of dynamic trunk and cushion pressure, fan dynamics, and trunk orifice flow. The separation point calculation is based on the diffuser model and no external spring is used. The input variables are shown in Figure 6 and the resulting printout is shown in Figure 7.

```
CARD NO.

 1 — 1.0,0.001,0.0
 2 — 0000000000000000
 3 — 03
 4 — DYNAMIC TEST 12 DEG Y=2.775 C-T-F WITH TRUNK FLOW DYN.
 5 — 1110000000000000
 6 — 16,0,50,2,1,0
 7 — 4.725,1.272,9.75,2.5
 8 — 18,50,59,60
 9 — 2.569,2.355
10 — 0.0,0.0,0.0,0.0,0.00616,0.00616,0.00616,0.00616
     0.00616,0.00616,0.00616,0.0,0.0,0.0,0.0,0.0
     0.0
11 — 0.88636,0.88636,0.44318,0.44318,0.44318,0.44318,0.44318,0.44318
     0.44318,0.44318,0.44318,0.44318,0.44318,0.44318,0.88636,0.88636
     0.88636
12 — 0.13573,0.68998,1.1196,1.5820,2.0711,2.5803,3.1022,3.6285
     4.1501,4.6451,5.0918,5.4731,5.7762,5.9915,6.1391,5.6379
13 — 0.96155,1.7605,2.0631,2.3131,2.5060,2.6377,2.7044,2.7023
     2.6299,2.4486,2.1678,1.8024,1.3692,0.88574,-0.082173,-0.92289
14 — 1.0135,1.0135,0.50675,0.50675,0.50675,0.50675,0.50675,0.50675
     0.50675,0.50675,0.50675,0.50675,0.50675,0.50675,1.0135,1.0135
```

Figure 6. Input data test case.

CARD NO.

```
15 —— 3926.0,3926.0,3926.0,3926.0,3926.0,3926.0,3926.0,3926.0
      3926.0,3926.0,3926.0,3926.0,3926.0,3926.0,3926.0,3926.0
      3926.0
16 —— 0.0,0.0,0.0,0.0,0.0,0.0,0.0,0.0
      0.0,0.0,0.0,0.0,0.0,0.0,0.0,0.0
17 —— 0.05,0.05,0.05,0.05,0.05,0.05,0.05,0.05
      0.05,0.05,0.05,0.05,0.05,0.05,0.05,0.05
18 —— 10.0,1.0
19 —— 0.0,0.0,0.0
20 —— 0.029,1041.0,245.0
21 —— -11224.0,61.4279,-.120792,1.05604E-4-3.524E-8
22 —— 1.0,0.50,1.0,-0.2094395
23 —— 2.775,0.5,2.775
24 —— 330.0,135.0,1446.0
26 —— 3XXXX3236404448
27 —— 0.0,0.99,0.005,0.0,0.0
26 —— 3XXXX7574800000
27 —— 0.0,0.99,0.005,0.0,0.0
26 —— 2XXXX7382000000
27 —— 0.0,0.99,0.005,0.0,0.0
```

Figure 6. Input data test case. (Continued)

```
 A SOLUTION  OF STATE EQUATIONS USING DYSYS

 MAXIMUM ORDER OF SYSTEM=100      INITIAL TIME= 0.          FINAL TIME=  1.000         TIME STEP= 1.00000E-03

DYNAMIC TEST 12 DEG Y=2.775 C-T-F WITH TRUNK FLOW DYN.

  1  1  1  0  0  0  0  0  0  0  0  0  0  0  0  0

OPTIONS IN EFFECT =
     DYNAMIC CUSHION PRESSURE
     DYNAMIC TRUNK-FAN PRESSURE
     TRUNK TO CHANNEL FLOW

 NODES,NSTATE,ICFLAG,IFXN,IFSEP INSEP,ILENG
   16        72          0        50          2          0          1
A,B,L,HYI
     4.72500      1.27200      9.75000      2.50000
SSLENG,TPERIM
   18.50000    59.60000
ATC,ATRIM
    2.56900      2.35500

 AREA TRUNK-GAP EACH ELEMENT
 0.          0.          0.          0.          .61600E-02  .61600E-02  .61600E-02  .61600E-02  .61600E-02  .61600E-02
  .61600E-02 0.          0.          0.          0.          0.          0.

 SPRING L 0
  .88636      .88636      .44318      .44318      .44318      .44318      .44318      .44318      .44318      .44318
  .44318      .44318      .44318      .44318      .88636      .88636      .88636


 NODE POSITIONS
X              Y

0.0000    0.0000
 .1357     .9616
 .6900    1.7605
1.1196    2.0631
1.5820    2.3131
2.0711    2.5060
2.5803    2.6377
3.1022    2.7044
3.6285    2.7023
4.1501    2.6299
4.6451    2.4486
5.0918    2.1687
5.4731    1.8024
5.7762    1.3692
5.9915     .8857
6.1391    -.0922
5.6379    -.9229
4.7250   -1.2720

 NODE ANGLES
  1.4306      .96430      .61364      .49564      .37567      .25309      .12711     -.39901E-02 -.13732     -.35109
 -.55975     -.76534     -.96929     -1.1518     -1.4195     -2.1084     -2.7763
```

Figure 7. Program output.

```
NODE MASSES
 .31501E-01  .31501E-01  .15750E-01  .15750E-01  .15750E-01  .15750E-01  .15750E-01  .15750E-01  .15750E-01  .15750E-01
 .15750E-01  .15750E-01  .15750E-01  .15750E-01  .31501E-01  .31501E-01

SPRING CONSTANTS
 3926.0      3926.0      3926.0      3926.0      3926.0      3926.0      3926.0      3926.0      3926.0      3926.0
 3926.0      3926.0      3926.0      3926.0      3926.0      3926.0      3926.0

BENDING STIFFNESS
 0.          0.          0.          0.          0.          0.          0.          0.          0.          0.
 0.          0.          0.          0.          0.          0.

NODE DAMPING
 .50000E-01  .50000E-01  .50000E-01  .50000E-01  .50000E-01  .50000E-01  .50000E-01  .50000E-01  .50000E-01  .50000E-01
 .50000E-01  .50000E-01  .50000E-01  .50000E-01  .50000E-01  .50000E-01

TREST,DAMPR
   10.00000     1.00000
 AIFAN,TKVOL,VCH
     .02903  1041.00000   245.00000
C00,C01,C02,C03,C04
 -11224.0       61.4279       -.120792        .165604E-03    -.352400E-07
 CTC,CTRIM,CGAP,TSEP
   1.00000      .50000     1.00000      -.20944
 YGRNDS,SRATIO,YDMIN
   2.77500      .50000     2.77500
 PTK,PCH
  339.00000   135.00000  1446.00000
TIME     0.00000
 NODE Y VALUES
 0.          .36155      1.7605      2.0631      2.3131      2.5060      2.6377      2.7044      2.7023      2.6299
 2.4436      2.1687      1.8024      1.3692      .88574     -.82173E-01 -.92289     -1.2720

 ICS,ISEP,INODE,YASEP,YGAPM,AGAP(ISEP),VEXIT,QEXIT,PCH,PTK,QFAN
   4   10    8     .14510     .07360      .14510    339.57361    49.27213   135.00000   330.00000  1446.00000
 XL,QTC,QTRIM,QCA,PCAVE,QTOT,QTA
   9.75000      0.00000     480.55739     397.19608     135.00000      28.58884     1064.08728
 NODE EXT PRESSURE
  135.00      134.96      134.87      134.73      133.67      123.30      106.21     -11.594     -82.832     -.98265E-01
 0.          0.          0.          0.          0.          0.          0.          0.

TIME      .05000
 NODE Y VALUES
 0.          .95338      1.7736      2.0597      2.2886      2.4636      2.5914      2.6712      2.6958      2.6226
 2.4073      2.0985      1.7086      1.2542      .75797     -.21951     -1.0219     -1.2720

 ICS,ISEP,INODE,YASEP,YGAPM,AGAP(ISEP),VEXIT,QEXIT,PCH,PTK,QFAN
   3   10    9     .15243     .07925      .15243    370.26177    56.44065   160.50319   326.89146  1444.68367
 XL,QTC,QTRIM,QCA,PCAVE,QTOT,QTA
  11.34527      0.00000     443.90426     790.29516     155.68069      38.45111     1018.67318
 NODE EXT PRESSURE
  160.50      160.34      159.97      159.46      157.19      150.26      125.30      27.173     -138.11      .31482
 0.          0.          0.          0.          0.          0.          0.          0.

TIME      .10000
 NODE Y VALUES
 0.          .35328      1.7308      2.0400      2.2987      2.5012      2.6431      2.7214      2.7324      2.6512
 2.4320      2.1326      1.7629      1.3357      .85894     -.10383     -.94232     -1.2720
```

Figure 7. Program output. (Continued)

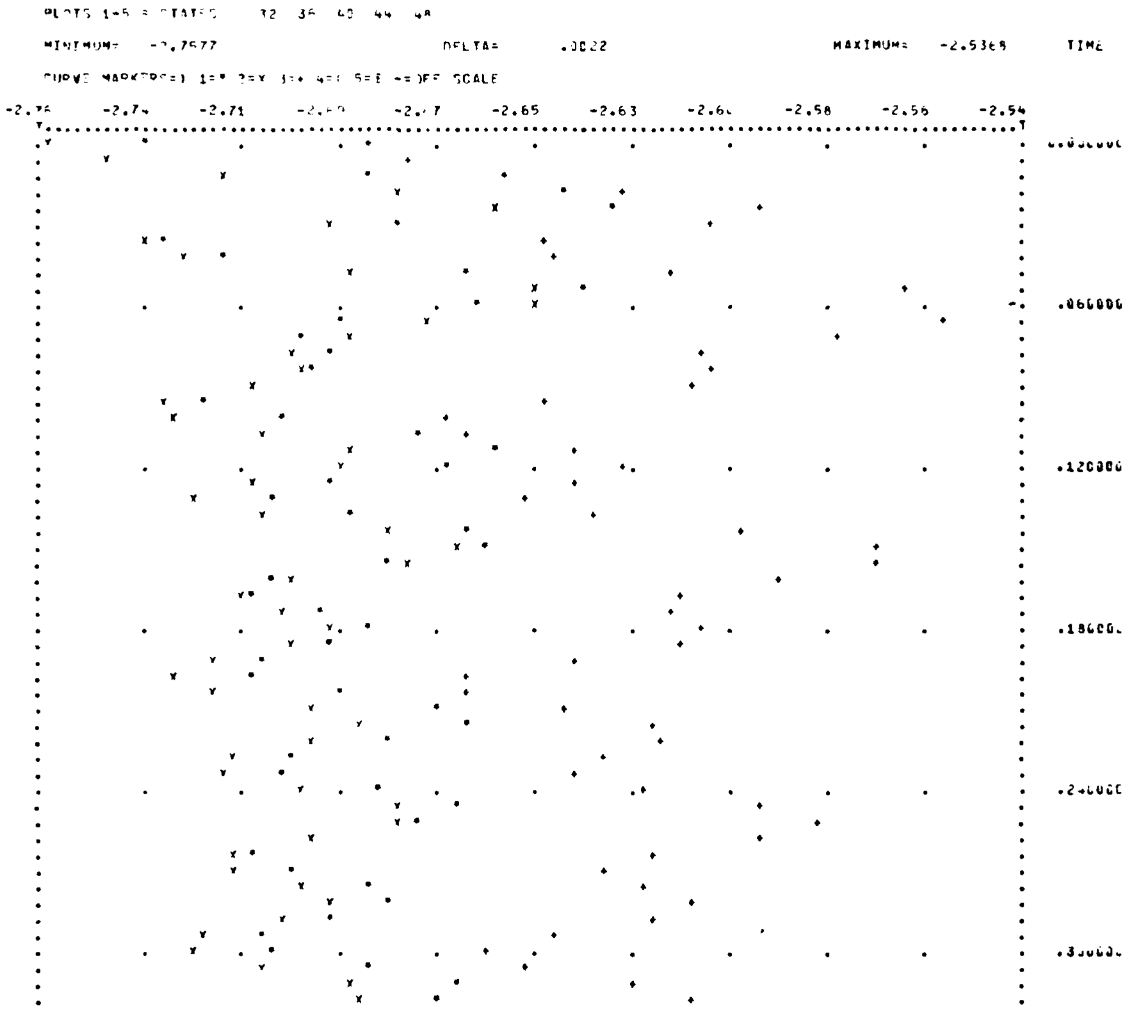


Figure 7. Program output. (Continued)

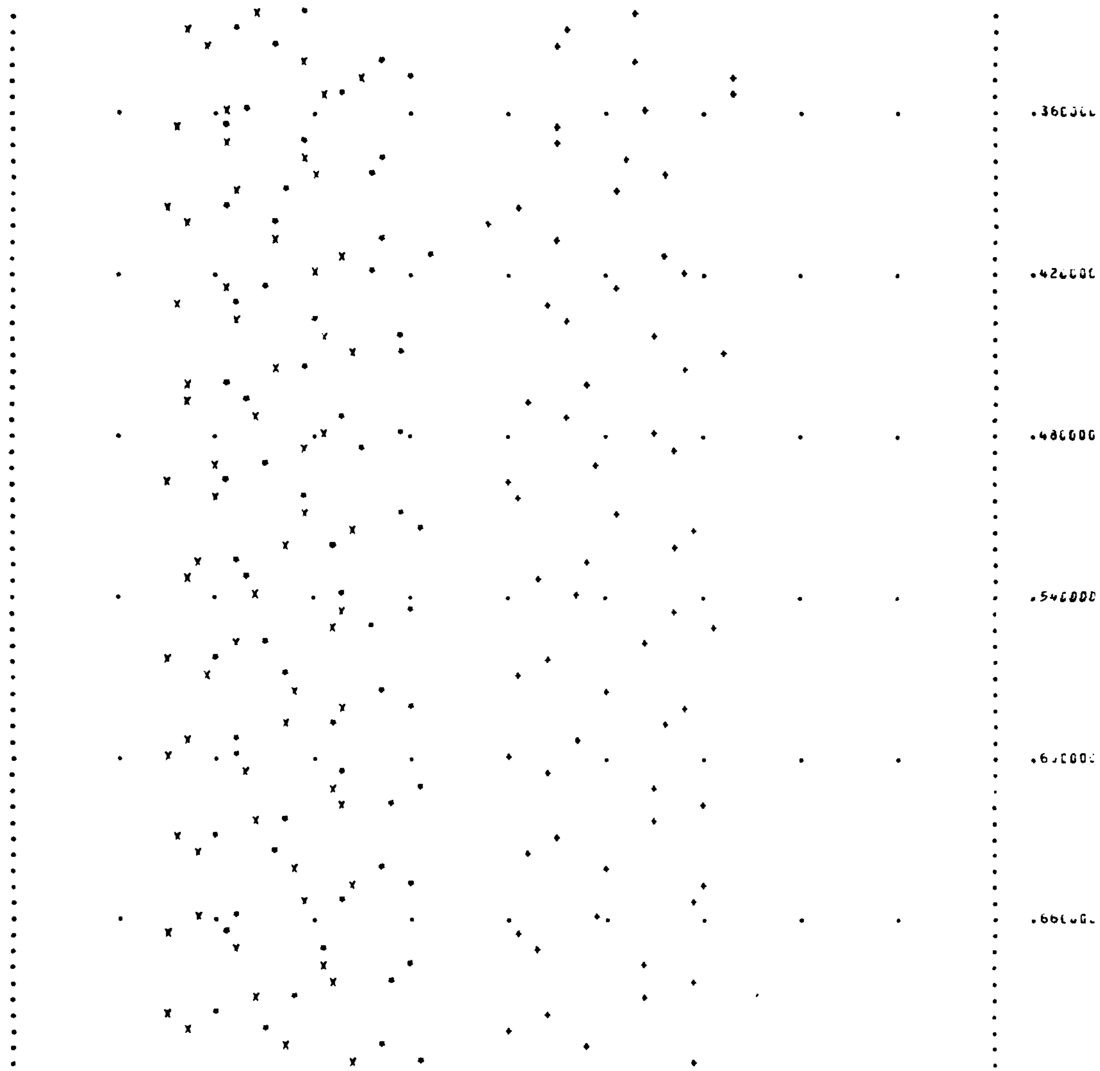


Figure 7. Program output. (Continued)

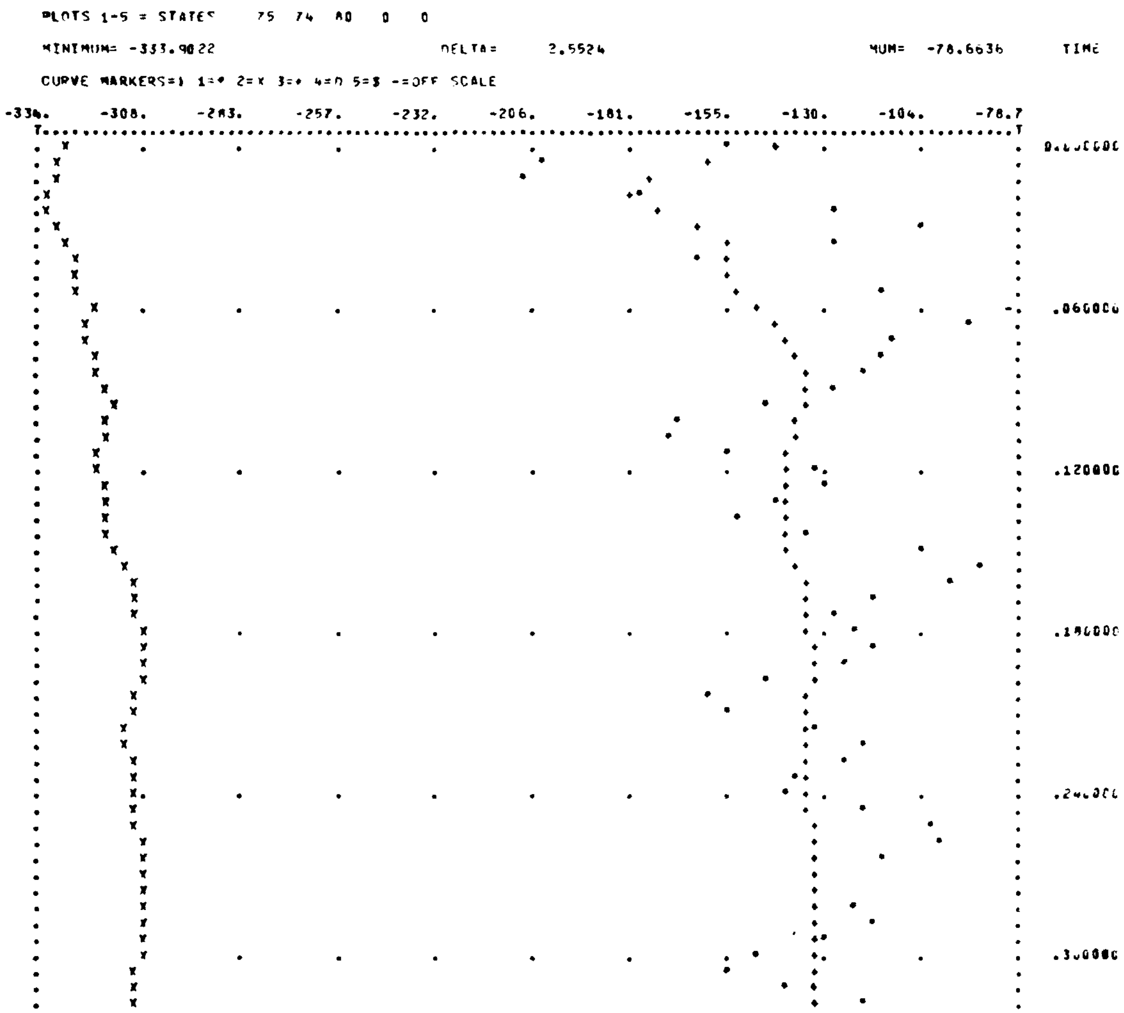


Figure 7. Program output. (Continued)

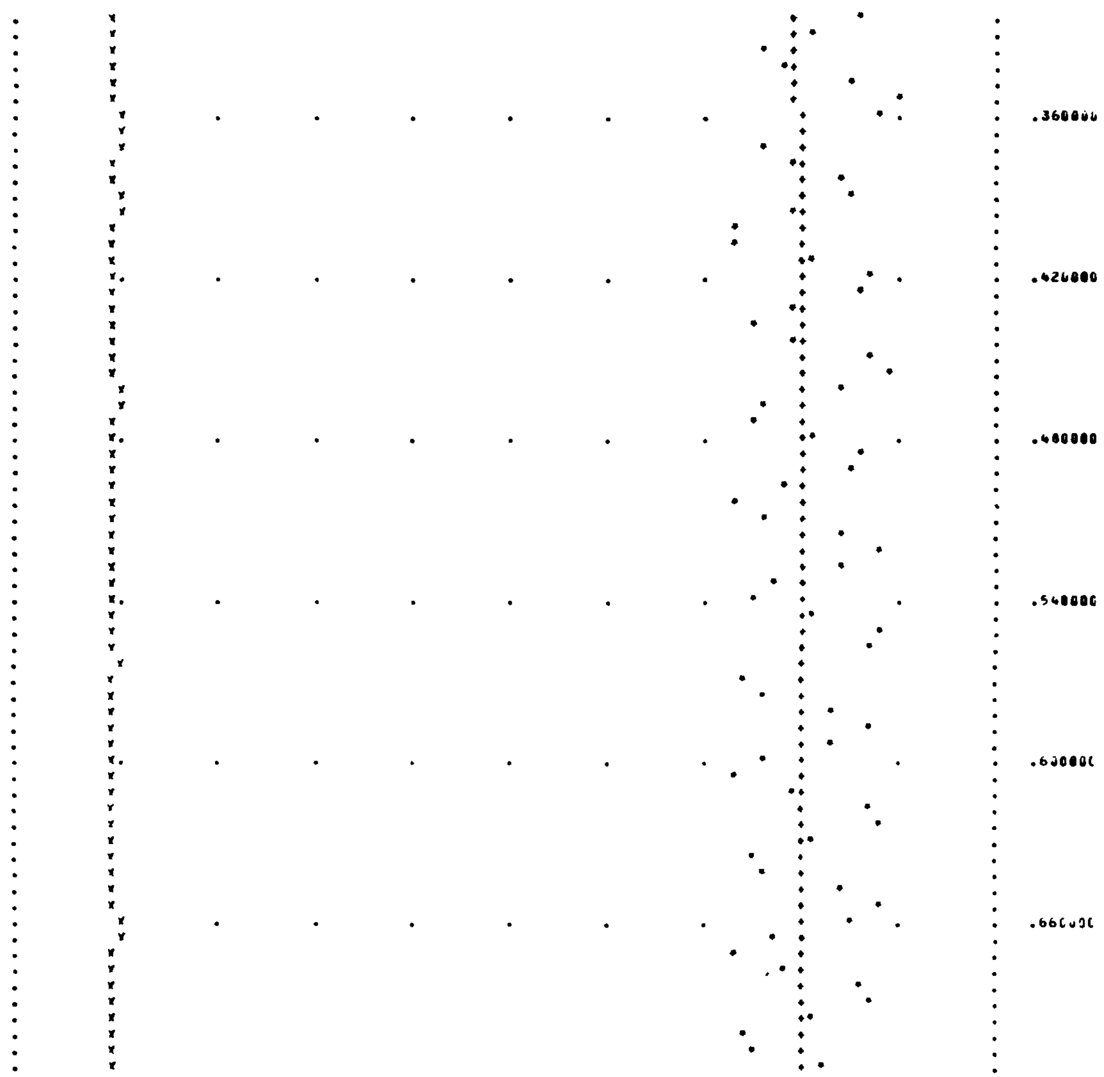


Figure 7. Program output. (Continued)

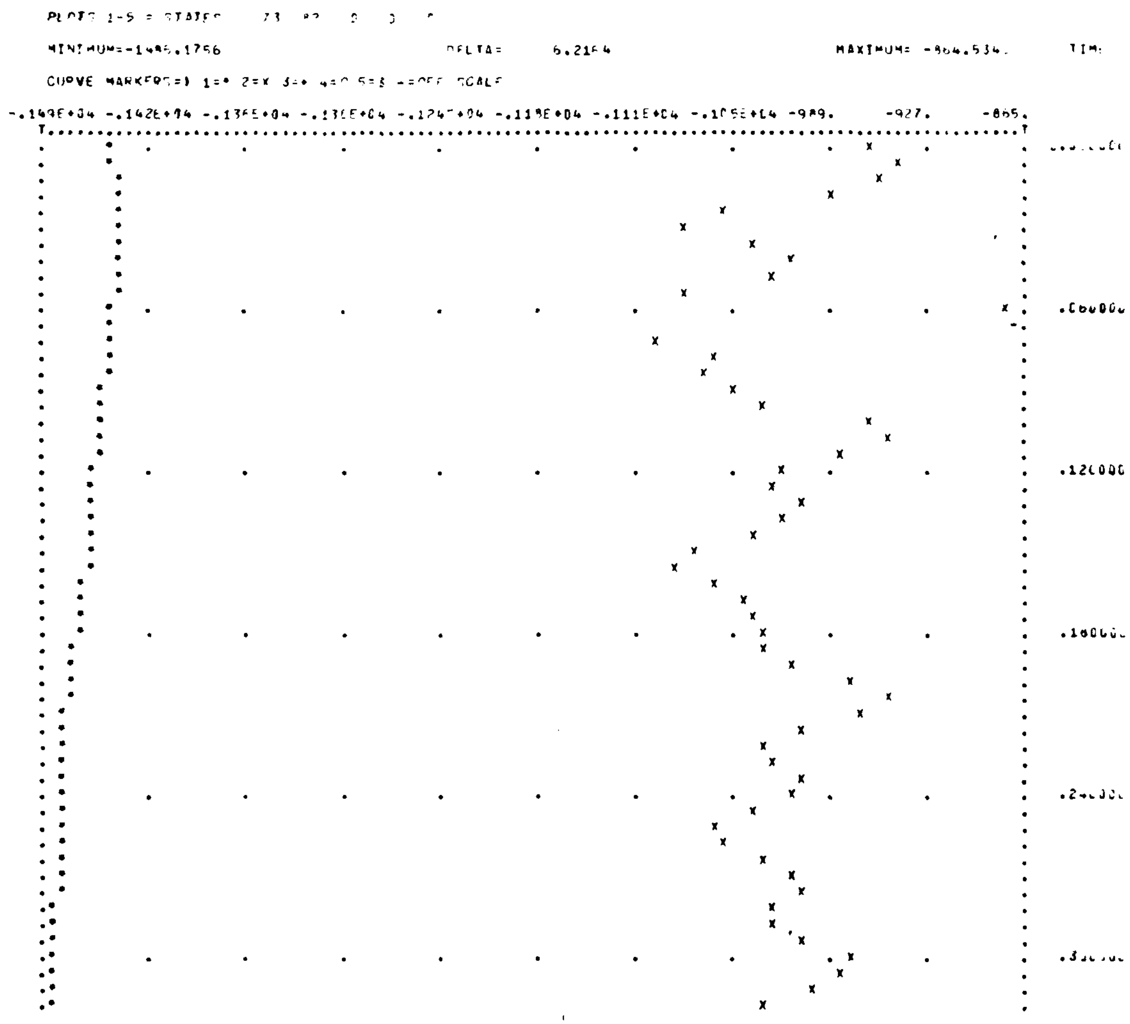


Figure 7. Program output. (Continued)

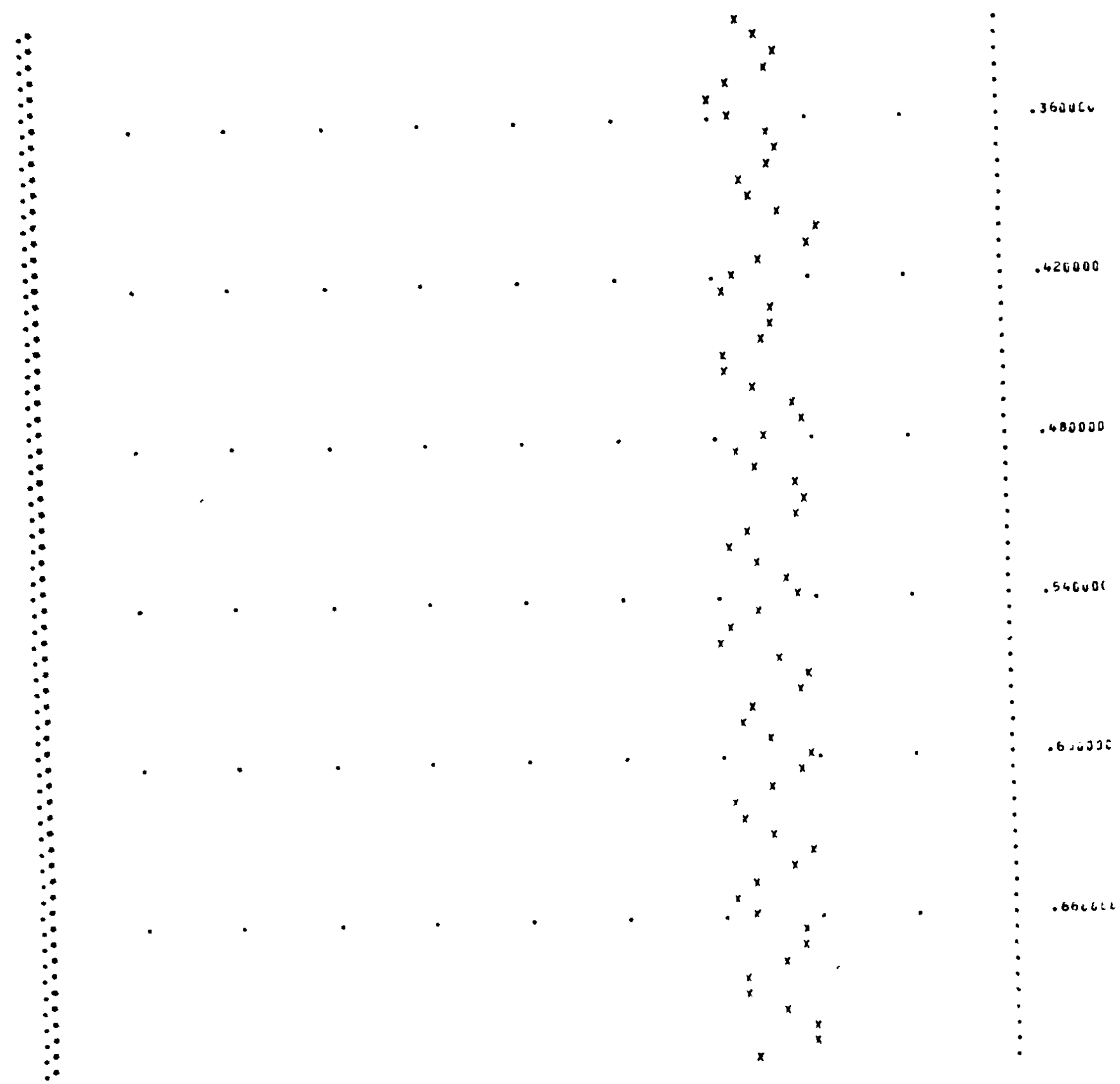


Figure 7. Program output. (Continued)

APPENDIX A

EQUATIONS USED IN THE MODEL

This program incorporates the nonlinear relationships between the motion of the lumped trunk masses and the system parameters, such as the trunk elasticity, damping and the pressure forces arising due to the fluid flow under the trunk, taking into account the geometry of the trunk. Figure A-1 shows a schematic diagram of the model. As shown in the model, the lumped masses are connected by springs representing elasticity of the trunk. Also included are the pressure forces acting between the lumped masses which are divided between the adjacent masses. The system damping is represented in this initial model by global dampers, which develop opposing forces proportional to the absolute velocities of the lumped masses.

The acceleration components of a trunk mass are calculated along the X and Y axes from summation of the stiffness, pressure and damping forces acting along the respective axes. Double integration of the accelerations gives positions which are then plotted to obtain instantaneous trunk shapes.

The equations used in the model are summarized in the following:

A.1 Geometry Relations (Figure A-2)

$$\theta_i = \mathrm{Tan}^{-1}\left((Y_{i+1} - Y_i)/(X_{i+1} - X_i)\right) \qquad \text{(A-1)}$$

$$\phi_i = \mathrm{Tan}^{-1}\left((Y_i - Y_{i+1})/(X_i - X_{i+1})\right) \qquad \text{(A-2)}$$

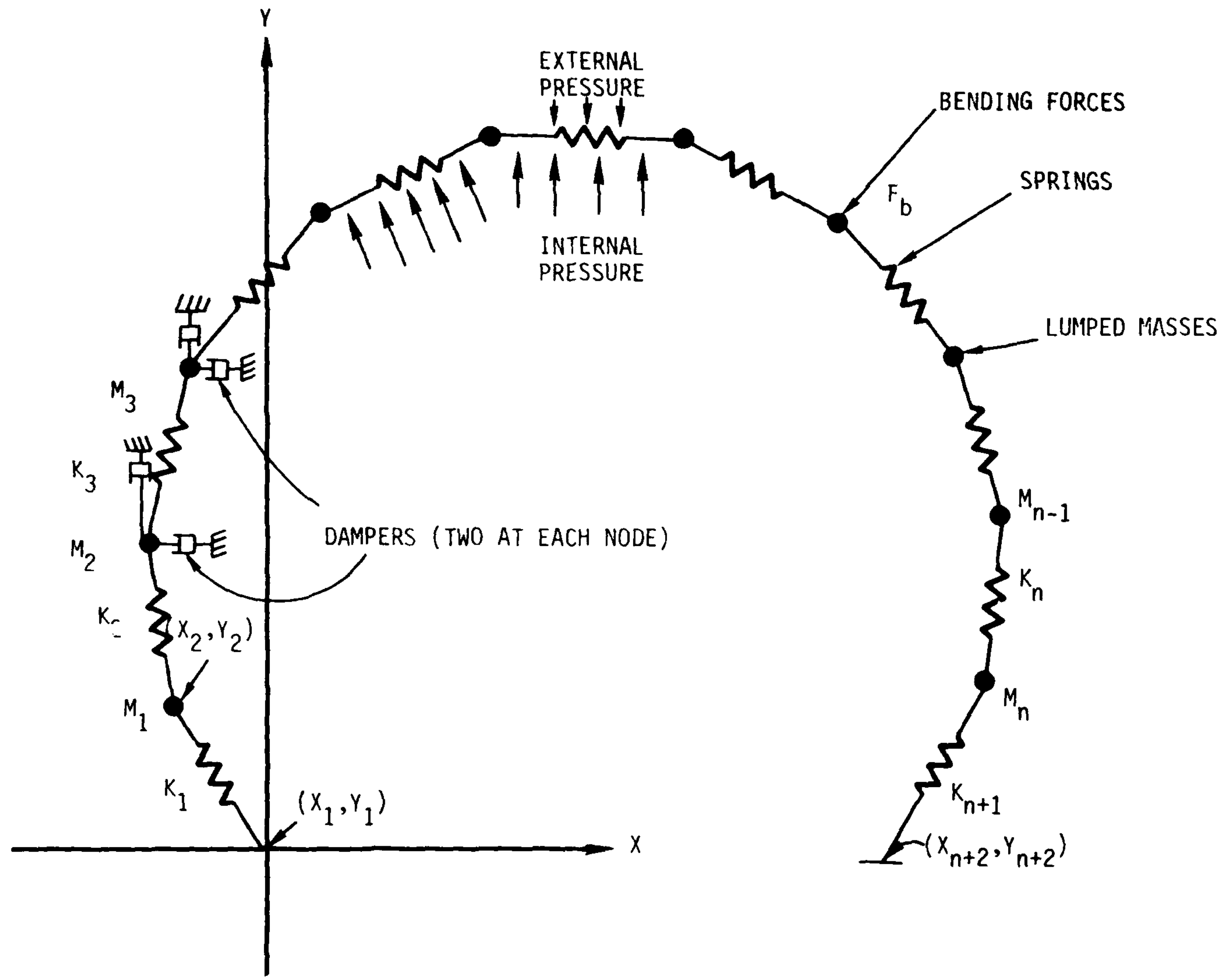


Figure A-1. Trunk representation for the dynamic simulation model.

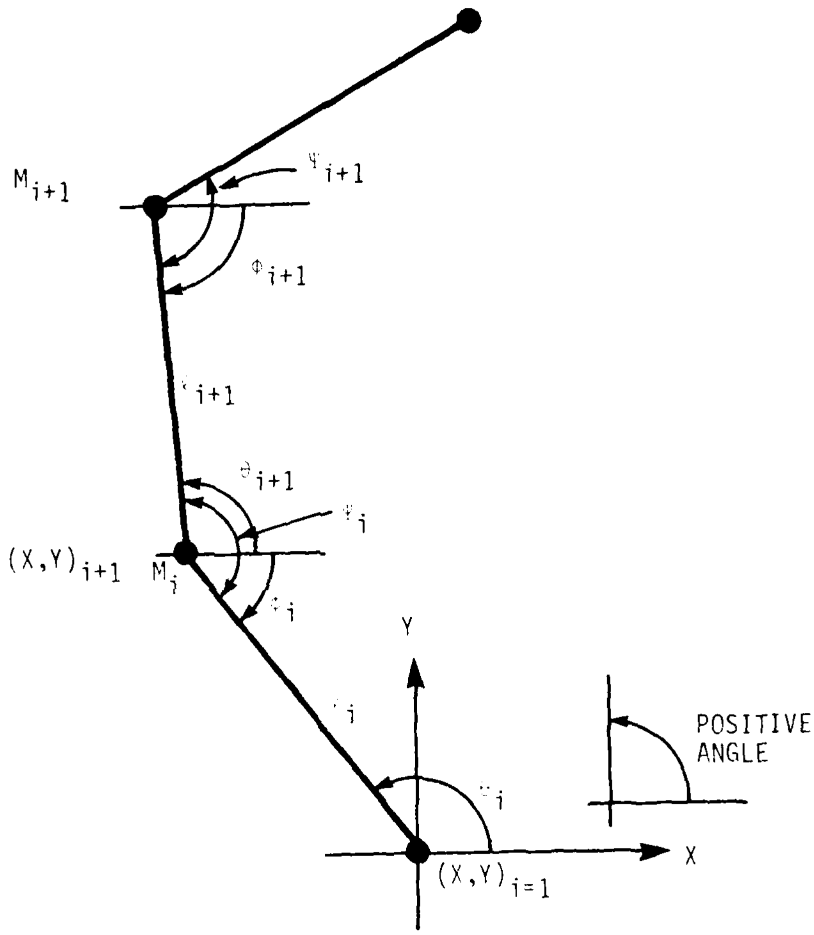


Figure A-2. The 2D coordinate system.

$$\ell_i = \sqrt{\left((X_{i+1} - X_i)^2 + (Y_{i+1} - Y_i)^2\right)} \qquad \text{(A-3)}$$

Note: Tan^{-1} is a four quadrant function, therefore, if $\theta = Tan^{-1}(\Delta Y/\Delta X), -\pi \leq \theta \leq \pi$.

A.2 Force Relations

<u>Spring Force</u> (Figure A-3)

$$F_{XK_i} = \cos(\phi_i)*K_i * \Delta\ell_i$$
$$+ \cos(\theta_{i+1})*K_{i+1} * \Delta\ell_{i+1} \qquad \text{(A-4)}$$

$$F_{YK_i} = \sin(\phi_i)*K_i * \Delta\ell_i$$
$$+ \sin(\theta_{i+1})*K_{i+1} * \Delta\ell_{i+1} \qquad \text{(A-5)}$$

where

$$\Delta\ell_i = \ell_i - \ell_{oi}$$

ℓ_{oi} (ℓ_{oi} is initial ℓ_i)

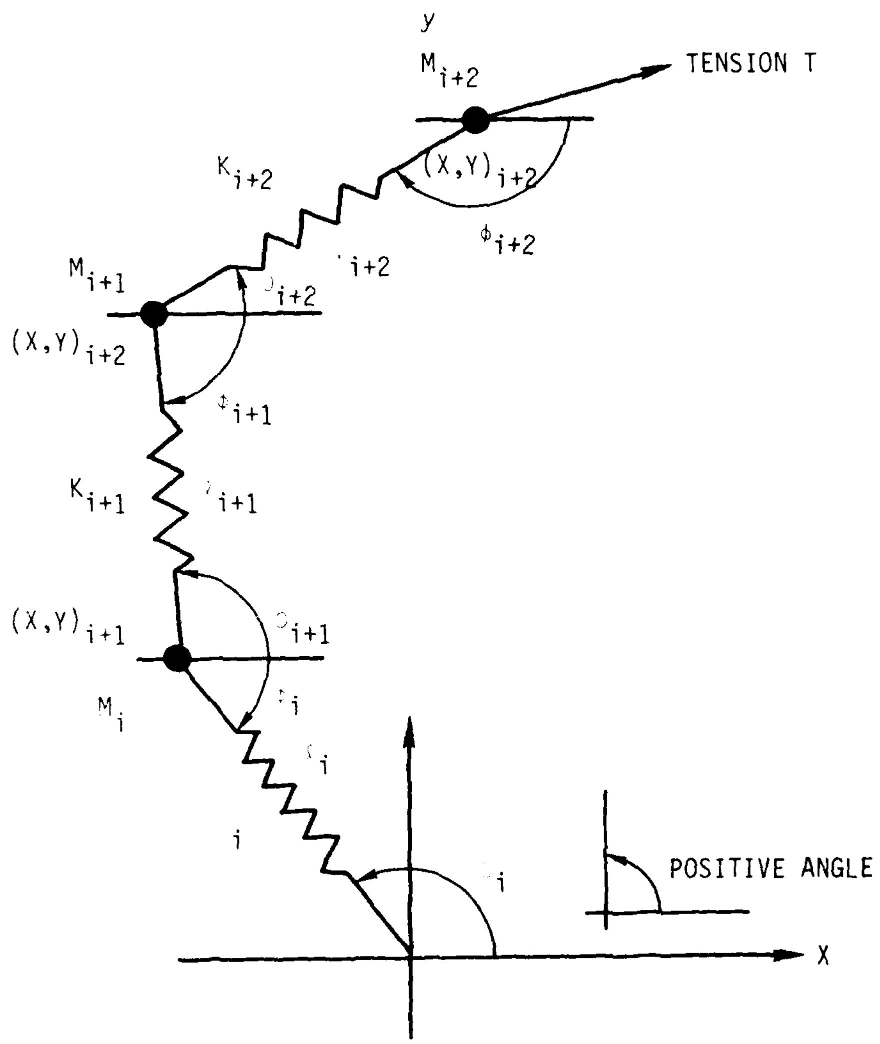


Figure A-3. Trunk elasticity representation.

Bending Forces (Figure A-4)

$$\text{TORQUE, } \tau = K_B * \Delta\psi$$

or

$$\tau = K_B * (\psi_o - \psi) \tag{A-6}$$

since

$$\tau = F * \ell$$

$$F * \ell = K_B(\psi_o - \psi)$$

$$F = \frac{K_B(\psi_o - \psi)}{\ell} \tag{A-7}$$

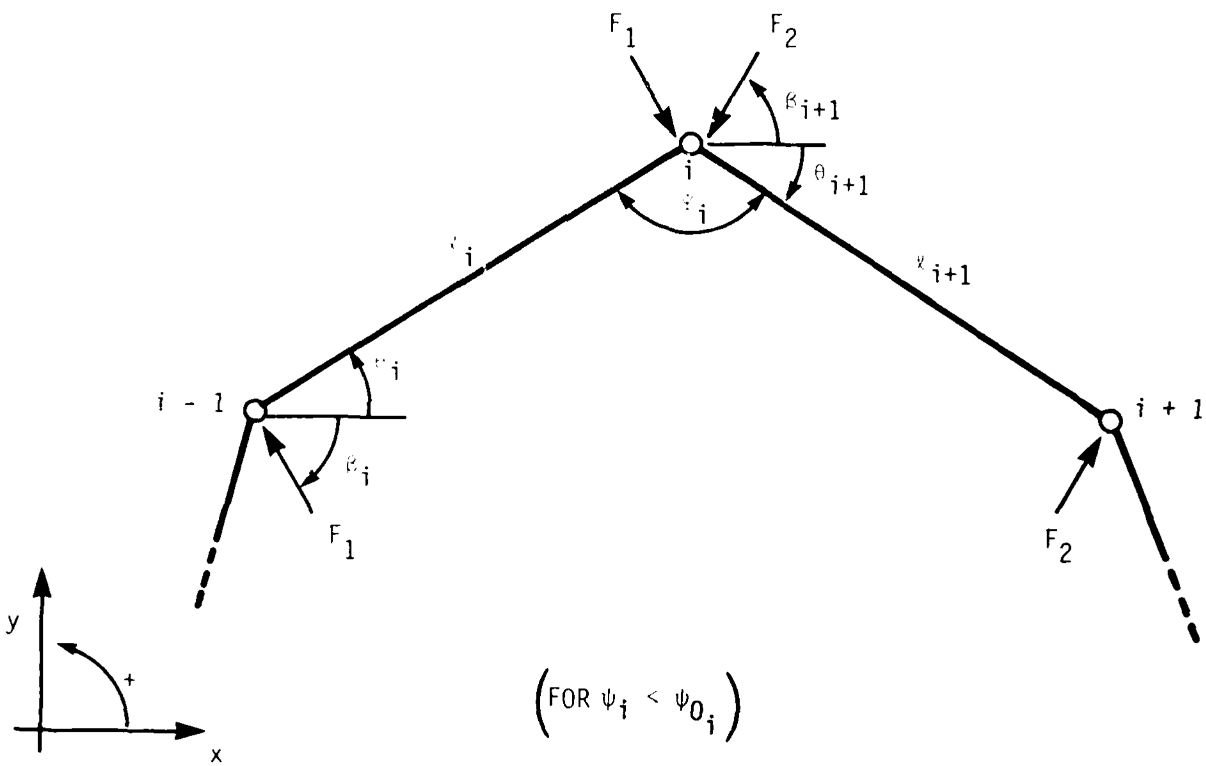
where

$$K_B = K_\ell * \frac{2}{\ell_1 + \ell_2}$$

so

$$F_1 = \frac{K_{\ell_i}(\psi_o - \psi)^2}{\ell_i(\ell_i + \ell_{i+1})} \tag{A-8}$$

$$F_2 = \frac{K_{\ell_i}(\psi_o - \psi)^2}{\ell_{i+1}(\ell_i + \ell_{i+1})} \tag{A-9}$$



$\left(\text{FOR } \psi_i < \psi_{0_i}\right)$

F_1 ORTHOGONAL TO ℓ_i

F_2 ORTHOGONAL TO ℓ_{i+1}

ψ_{o_i} = INITIAL "NO BENDING" NODE ANGLE

(ALL ANGLES ARE (+) COUNTERCLOCKWISE ROTATION)

Figure A-4. Bending force representation.

Converting forces F_1 and F_2 into component F_X, F_Y forces at each node (i) gives (see Figure A-5)

$$F_{X_i} = -F_1 \cos(\beta_i) \tag{A-10}$$

$$F_{Y_i} = -F_1 \sin(\beta_i) \tag{A-11}$$

$$F_{X_{i+1}} = -F_1 \cos(\beta_i + \pi) - F_2 \cos(\beta_{i+1}) \tag{A-12}$$

$$F_{Y_{i+1}} = -F_1 \sin(\beta_i + \pi) - F_2 \sin(\beta_{i+1}) \tag{A-13}$$

$$F_{X_{i+2}} = -F_2 \cos(\beta_{i+1} + \pi) \tag{A-14}$$

$$F_{Y_{i+2}} = -F_2 \sin(\beta_{i+1} + \pi) \tag{A-15}$$

Due to orthoganality:

$$\beta_i = \theta_i - \frac{\pi}{2} \tag{A-16}$$

$$\beta_{i+1} = \theta_{i+1} - \frac{\pi}{2} \tag{A-17}$$

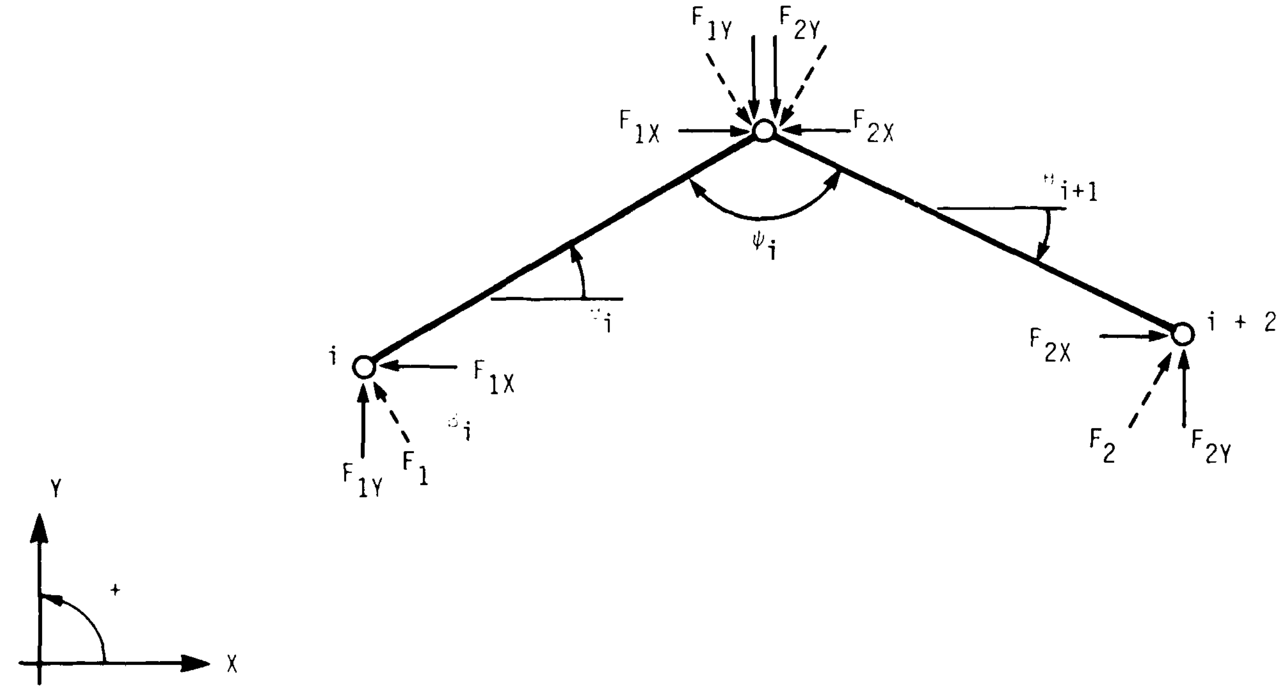


Figure A-5. Bending force vectors.

From trigonometric identities:

$$\cos(\theta_i - \frac{\pi}{2}) = \sin(\theta_i) \tag{A-18}$$

$$\sin(\theta_i - \frac{\pi}{2}) = -\cos(\theta_i) \tag{A-19}$$

$$\cos(\theta_i + \frac{\pi}{2}) = -\sin(\theta_i) \tag{A-20}$$

$$\sin(\theta_i + \frac{\pi}{2}) = \cos(\theta_i) \tag{A-21}$$

So replacement of β terms with equivalent θ terms gives:

$$F_{X_i} = -F_1 \sin(\theta_i) \tag{A-22}$$

$$F_{Y_i} = -F_1 \left[-\cos(\theta_i)\right] \tag{A-23}$$

$$F_{X_{i+1}} = -F_1 \left[-\sin(\theta_i)\right] - F_2 \sin(\theta_{i+1}) \tag{A-24}$$

$$F_{Y_{i+1}} = -F_1 \cos(\theta_i) - F_2 \left[-\cos(\theta_{i+1})\right] \tag{A-25}$$

$$F_{X_{i+2}} = -F_2 \left[-\sin(\theta_{i+1})\right] \tag{A-26}$$

$$F_{Y_{i+2}} = -F_2 \cos(\theta_{i+1}) \quad \text{(A-27)}$$

Reducing the equations leads to:

$$F_{X_i} = -F_1 \sin(\theta_i) \quad \text{(A-28)}$$

$$F_{Y_i} = F_1 \cos(\theta_i) \quad \text{(A-29)}$$

$$F_{X_{i+1}} = F_1 \sin(\theta_i) - F_2 \sin(\theta_{i+1}) \quad \text{(A-30)}$$

$$F_{Y_{i+1}} = -F_1 \cos(\theta_i) + F_2 \cos(\theta_{i+1}) \quad \text{(A-31)}$$

$$F_{X_{i+2}} = F_2 \sin(\theta_{i+1}) \quad \text{(A-32)}$$

$$F_{Y_{i+2}} = -F_2 \cos(\theta_{i+1}) \quad \text{(A-33)}$$

Attached Spring Forces

If an external spring is attached to node I to suppress flutter, it creates a generalized force $F_G(I)$.

$$F_G = -K_{EXT}\,\Delta D \tag{A-34}$$

In X, Y components:

$$F_{XG_i} = -K_{EXT} * \Delta X_i \tag{A-35}$$

$$F_{YG_i} = -K_{EXT} * \Delta Y_i \tag{A-36}$$

where

$$-\Delta X_i = (X_{o_i} - X_i) \tag{A-37}$$

$$-\Delta Y_i = (Y_{o_i} - Y_i) \tag{A-38}$$

therefore

$$F_{XG_i} = K_{EXT}\,(X_{o_i} - X_i) \tag{A-39}$$

$$F_{YG_i} = K_{EXT}\,(Y_{o_i} - Y_i) \tag{A-40}$$

Pressure Force (Figure A-6)

Defining

$$P_i = P_{tk} - P_{ext_i} \tag{A-41}$$

where P_{tk} = Internal Pressure on Membrane
and P_{ext_i} = External Pressure on Membrane (static or dynamic)
leads to pressure forces at node points:

$$F_{XP_i} = \frac{-P_i}{2}\left[\ell_i * \sin(\theta_i) + \ell_{i+1} * \sin(\theta_{i+1})\right] \tag{A-42}$$

$$F_{YP_i} = \frac{P_i}{2}\left[\ell_i * \cos(\theta_i) + \ell_{i+1} * \cos(\theta_{i+1})\right] \tag{A-43}$$

Damper Forces (Figure A-7)

$$\text{By definition } \bar{F} = D \cdot \bar{V} \tag{A-44}$$

$$F_{XD_i} = V_{x_i} * \xi_i * 2 \sqrt{M_i * K_i} \tag{A-45}$$

$$F_{YD_i} = V_{y_i} * \xi_i * 2 \sqrt{M_i * K_i} \tag{A-46}$$

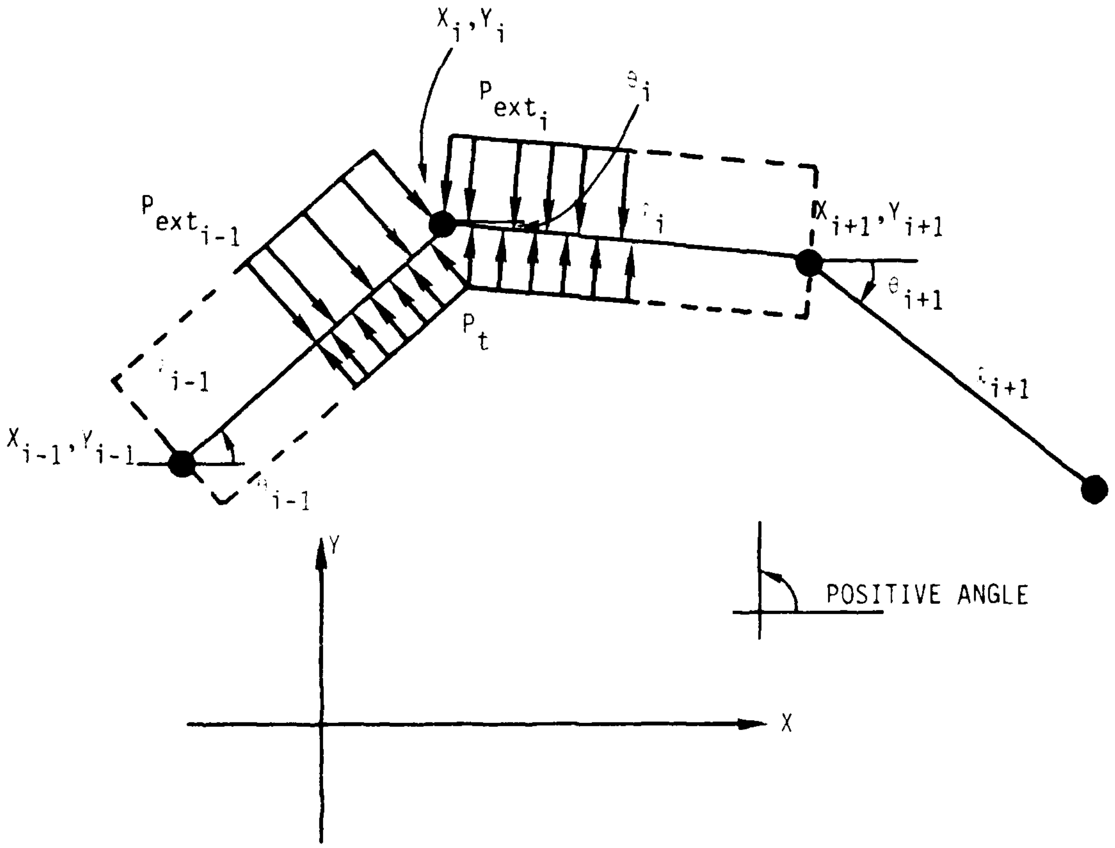


Figure A-6. Pressure force representation.

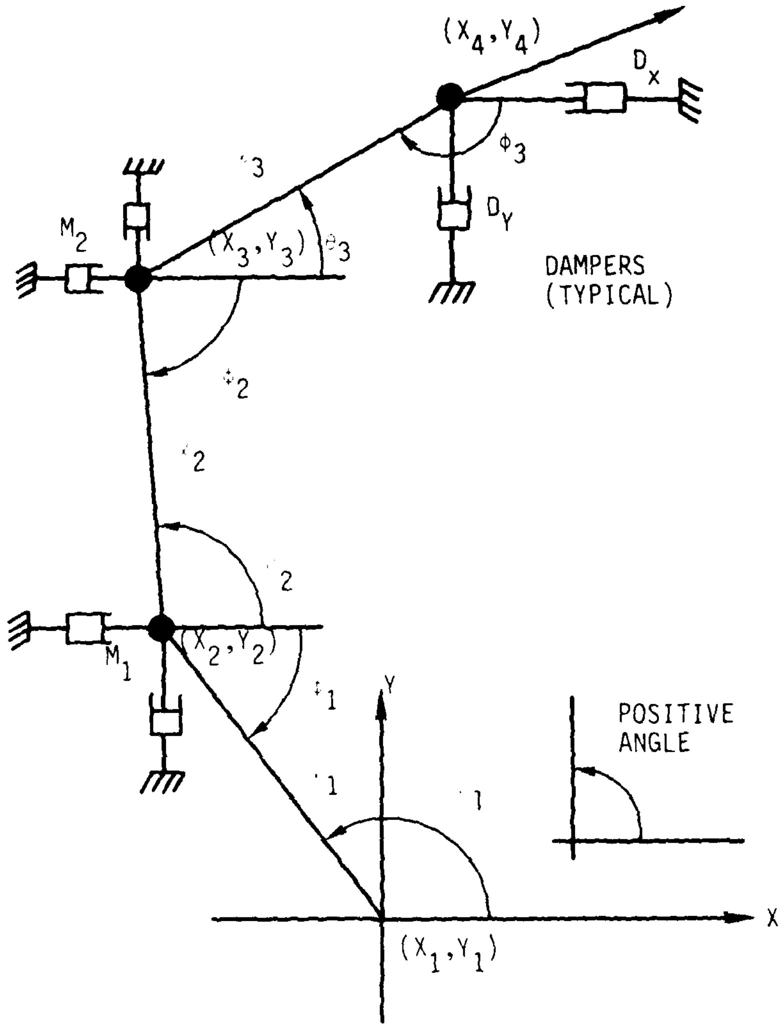


Figure A-7. Damping representation.

where

ξ_i = damping ratio at node i
M_i = nodal mass at node i
K_i = average stiffness at node i

Differential Equations:

$$\frac{d^2X_i}{dt^2} = (F_{xd_i} + F_{xk_i} + F_{xp_i} + F_{xb_i} + F_{xG_i})/M_i \qquad \text{(A-47)}$$

$$\frac{d^2Y_i}{dt^2} = (F_{yd_i} + F_{yk_i} + F_{yp_i} + F_{yb_i} + F_{yG_i})/M_i \qquad \text{(A-48)}$$

$$\frac{dX_i}{dt} = \dot{X}_i \qquad \text{(A-49)}$$

$$\frac{dY_i}{dt} = \dot{Y}_i$$

A.3 Flow Relations

Pressure - Flow Relationship (Figure A-8)

Dynamic pressure under membrane modelled by Bernoulli flow equation for ideal flow with no trunk flow.

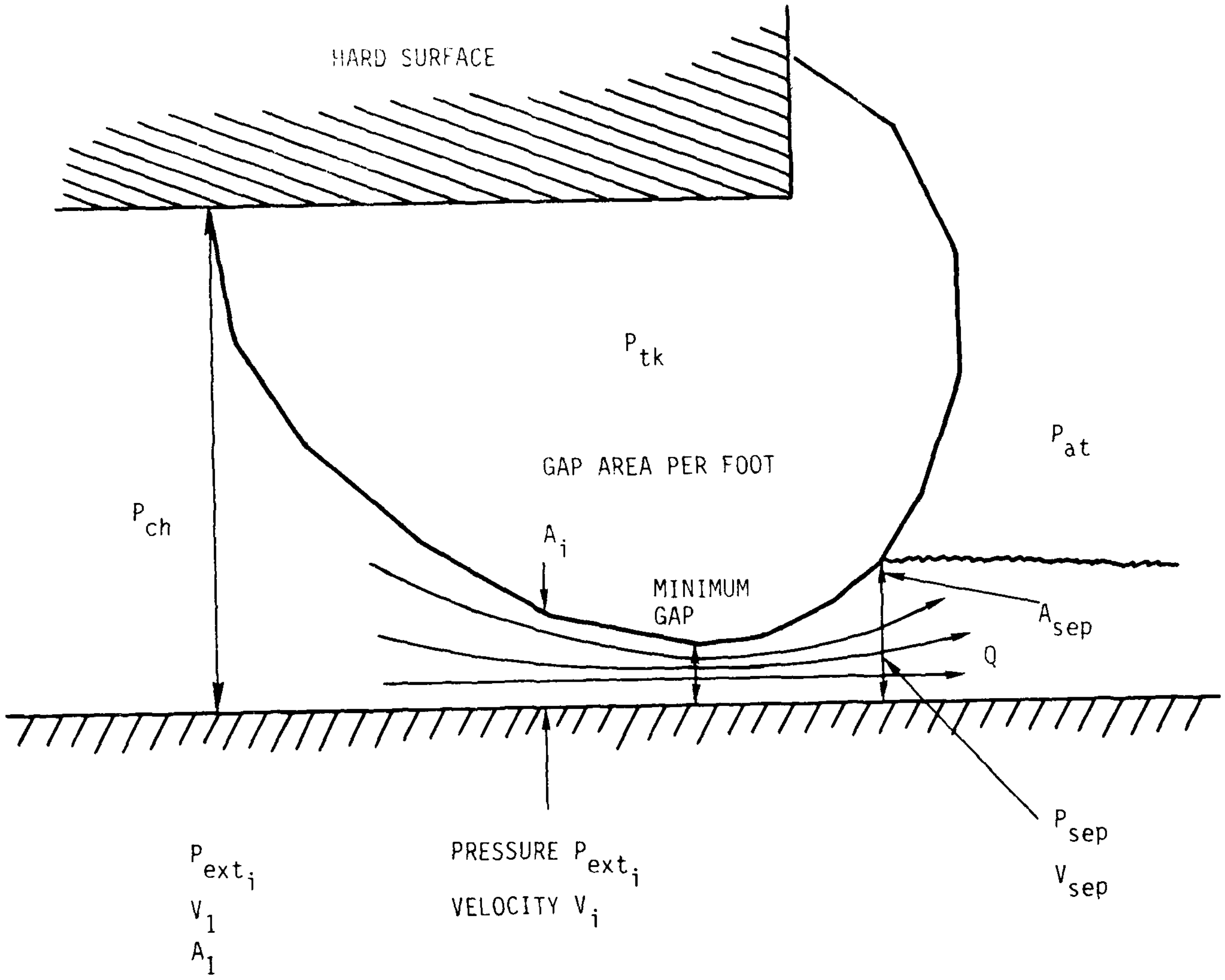


Figure A-8. Fluid flow representation.

$$\frac{P_1}{\rho} + \frac{V_1^2}{2} = \frac{P_2}{\rho} + \frac{V_2^2}{2} \tag{A-51}$$

where

$$Q = V_i A_i = V_2 A_2 = V_{sep} A_{sep} \tag{A-52}$$

therefore

$$P_{ext_i} - P_{sep} = \rho \frac{V_{sep}^2}{2} \left[1 - \left(\frac{A_{sep}}{A_i}\right)^2\right] \tag{A-53}$$

at separation point

$$P_{sep} = P_{at} = 0$$

$$P_1 = P_{ch}, \; V_1 = 0$$

Therefore,

$$\frac{P_{ch}}{\rho} = \frac{V_{sep}^2}{2} \tag{A-54}$$

or

$$V_{sep} = \sqrt{\frac{2P_{ch}}{\rho}} \qquad \text{(A-55)}$$

since

$$Q = A_{sep} \sqrt{\frac{2P_{ch}}{\rho}} = A_{sep} * V_{sep} \qquad \text{(A-56)}$$

therefore

$$P_i = P_{ch} \left(1 - \left(\frac{A_{sep}}{A_i}\right)^2\right) \qquad \text{(A-57)}$$

Pressure Source Dynamics

The system model includes the capabilities of fan-trunk-cushion dynamics shown in Figure A-9. The fan includes a pressure versus flow polynomial curve fit and a fluid model of the trunk and cushion volumes and orifices. (See final report for derivation of equations A-58 through A-61).

Differential Equations:

$$\frac{d}{dt} (Q_{FAN}) = \frac{P(Q_{FAN}) - P_{tk}}{I_{FAN}} \qquad \text{(A-58)}$$

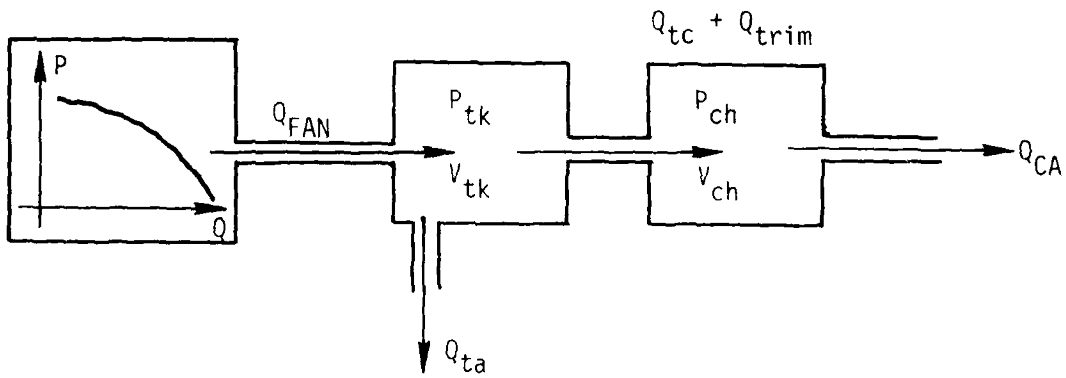


Figure A-9. Dynamic fluid model.

$$\frac{d}{dt}(P_{TK}) = \frac{C_{KK}}{V_{TK}}(P_{TK} + P_{AT}) * (Q_{FAN} - Q_{TC} - Q_{TA} - Q_{TRIM}) \quad \text{(A-59)}$$

$$\frac{d}{dt}(P_{CH}) = \frac{C_{KK}}{V_{CH}}(P_{CH} + P_{AT}) * (Q_{TC} - Q_{TRIM} - Q_{CA}) \quad \text{(A-60)}$$

where,

$$P(Q_{FAN}) = CQ_0 + CQ_1 * Q_{FAN} + CQ_2 * Q_{FAN}^2$$
$$+ CQ_3 * Q_{FAN}^3 + CQ_4 * Q_{FAN}^4 \quad \text{(A-61)}$$

(See Figure A-10).

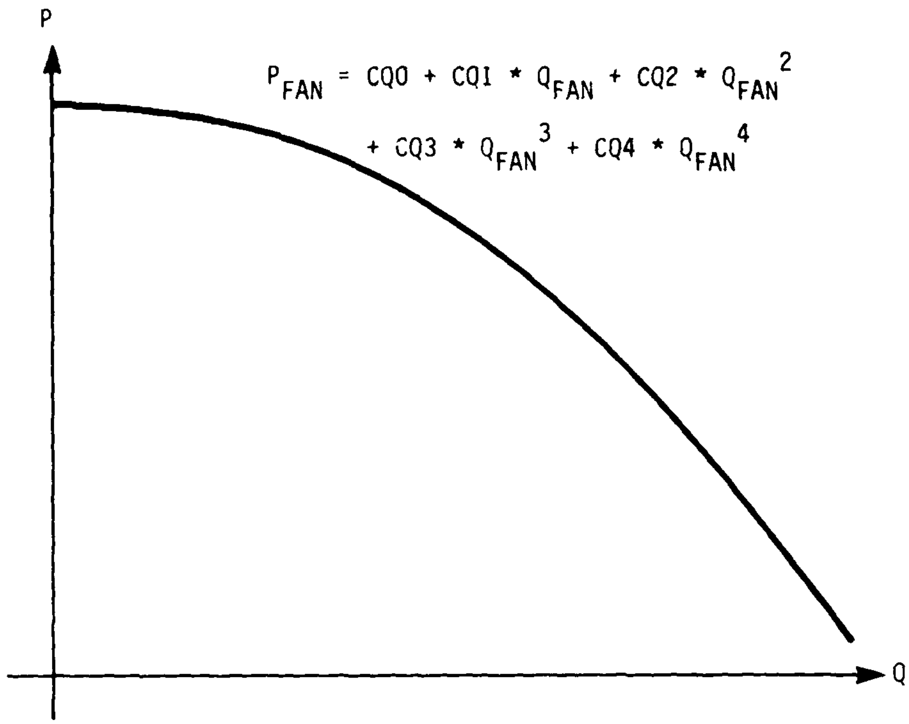


Figure A-10. Fan pressure versus flow polynomial.

The flow model determines the variations in pressures and flows as a function of time. There are two parts to the flow model: the fluid chambers (that is, cushion and trunk), and the fan. The principal assumptions of the flow model are as follows.

a. The flow through all orifices is one-dimensional and quasi-static, that is, the pressure in the plane of the orifice is uniform, and the unsteady state terms in Bernoulli's equation are small compared to the change in velocity head.

b. The flow through the orifices is incompressible, that is, the pressure drop is small compared to the total pressure, and the air density is constant.

c. The pressure and volume changes of the air during expansion and compression in the various fluid chambers are governed by a polytropic relationship, that is, pv^k = const..

Trunk Orifice Flow Effects:

The addition of flow from the trunk orifice to the gap changes the pressure profile under the trunk. The flow/pressure relations are iteratively computed between the cushion and the separation point. The flow is computed by considering a number of control volumes between nodes. (see Figure A-11).

The flow into each control volume is computed as:

$$Q_{TC_i} = C_{TC} * A_{TC_i} * \sqrt{\frac{2\left[P_{tk} - (P_i + P_{i+1})/2\right]}{\rho}} \qquad \text{(A-62)}$$

$$dW_i = \rho * Q_{TC_i} \qquad \text{(A-63)}$$

$$W_{i+1} = W_i + dW \qquad \text{(A-64)}$$

then a new P_{i+1} is computed

$$P_{i+1} = P_{ch} - \frac{\rho}{2} * V_i^{\,2} - \int_0^x \frac{V_i \; dW}{A_i} \, dx \qquad \text{(A-65)}$$

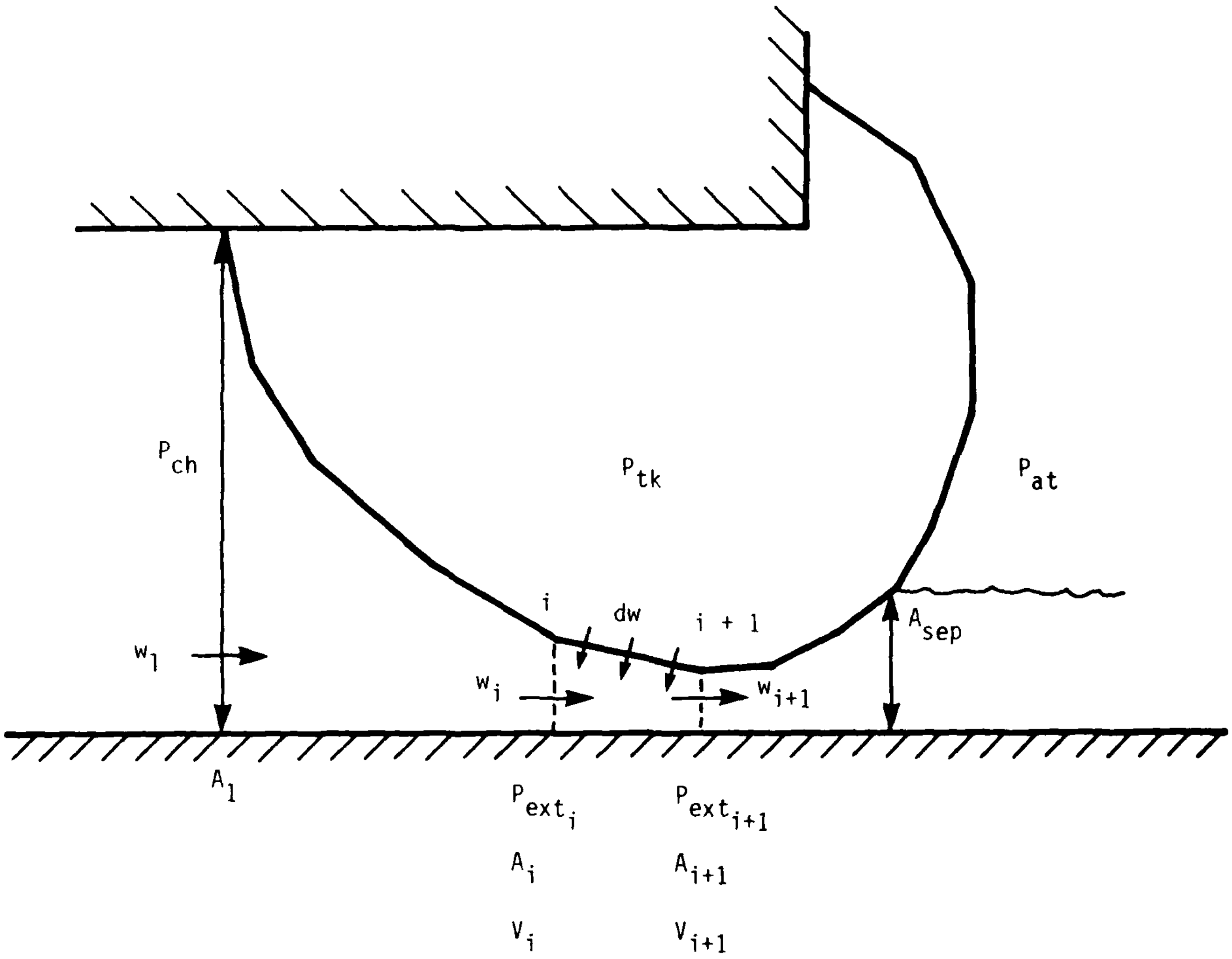


Figure A-11. Trunk flow analysis.

The flow-pressure pattern is computed under the trunk step-by-step out to the separation point. The flow computation is iterated by varying W(1) until the exit pressure at the separation point is within bounds.

APPENDIX B

THE EIGENVALUE PROGRAM

This program was developed as a part of the contract. By generating eigenvalues and eigenvectors of the trunk for various models, this program can assist in understanding the trunk behavior.

B.1 Program Description

The eigenvalue program has three parts. The first part analyzes the two dimensional vibration of a membrane using coupled longitudinal and lateral motions including tension and elasticity effects. The second part analyzes vibration of a membrane which does not have longitudinal motion and vibrates only in the lateral direction similar to a stretched string. The third part of the program is relevant for an elastic membrane which can vibrate only in the longitudinal direction. This mode of vibration is similar to that of a bar. The program can work with damped or undamped systems. In addition, the program calculates the natural frequencies for an equivalent string. The output of the program consists of the eigenvalues and eigenvectors (optional).

A list of the subroutines used is presented in Table B-1. The input data description for the program and a sample output are also presented in this Appendix. However, first the various models used in the program are described in Table B-1.

TABLE B-1. A SUMMARY OF EIGENVALUE PROGRAM SUBROUTINES

No.	Subroutine	Primary Function	Group
1	FMAEVEC	Main program; I/O control, coordinate analysis; form matrices	*MAIN*
2	CLEAR	Clear matrix to zero	MATRIX
3	PUTMAT	Print matrix	I/O
4	TRUNK	Computer trunk shape	GEOMETRY
5	ELEMK	Form element stiffness matrix	GEOMETRY
6	MOVE	Copy matrix	MATRIX
7	EIGPAC	Eigenvalue/eigenvector computation coordination module	EIGEN
8	CMINV	Complex matrix inversion	MATRIX
9	PUTEIG	Print eigenvalues	I/O
10	HSBG	SSP eigenvalue routine	EIGEN
11	ATEIG	SSP eigenvalue routine	EIGEN
12	VECPAC	Eigenvector computation and output coordination module	EIGEN
13	EVECTR	Solve complex system of equations	EIGEN

B.2 Models Used in the Eigenvalue Program

B.2.1 Lateral Vibration Model

In Figure B-1, the force due to displacement Y_p is:

$$F_p = -T \sin(\alpha_{p-1}) + T \sin(\alpha_p) \qquad \text{(B-1)}$$

For a first order approximation,

$$\sin(\alpha_{p-1}) \simeq \frac{y_p - y_{p-1}}{\ell_{p-1}}$$

$$\sin(\alpha_p) \simeq \frac{y_{p+1} - y_p}{\ell_p}$$

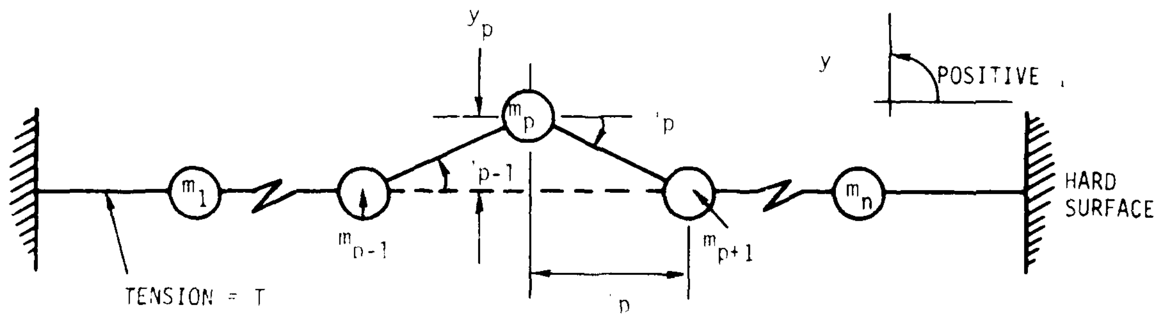


Figure B-1. Lateral vibration model.

therefore,

$$F_p = -\frac{T}{\ell_{p-1}}(y_p - y_{p-1}) + \frac{T}{\ell_p}(y_{p+1} - y_p). \qquad \text{(B-2)}$$

From $\quad \bar{F} = M\bar{A}$

$$F_p = m_p \frac{d^2 y_p}{dt^2}$$

$$\frac{d^2 y_p}{dt^2} = \frac{-T}{m_p \ell_{p-1}}(y_p - y_{p-1}) + \frac{T}{m_p \ell_p}(y_{p+1} - y_p), \qquad \text{(B-3)}$$

let

$$\lambda_p = \omega_p^2 = \frac{T}{m_p \ell} : \text{ for } \ell_p = \ell_{p-1} = \ell$$

Then,

$$\frac{d^2 y_p}{dt^2} + 2\omega_p^2 y_p - \omega_p^2 (y_{p+1} + y_{p-1}) = 0 \qquad \text{(B-4)}$$

where the boundary conditions are:

$$y_o = y_{n+1} = 0.$$

Writing equation (B-4) in a Matrix form:

$$\ddot{\underline{Y}} + \underline{\lambda} Y = 0$$

$$\begin{bmatrix} \ddot{y}_1 \\ \ddot{y}_2 \\ \ddot{y}_3 \\ \cdot \\ \cdot \\ \cdot \\ \ddot{y}_n \end{bmatrix} + \begin{bmatrix} 2\lambda_1, -\lambda_1, & 0\ldots0 \\ -\lambda_2, 2\lambda_2, -\lambda_2, & 0\ldots0 \\ 0, -\lambda_3, 2\lambda_3, -\lambda_3, & 0\ldots0 \\ \cdot & \\ \cdot & \\ \cdot & \\ 0\ldots0, & -\lambda_n, 2\lambda_n \end{bmatrix} * \begin{bmatrix} y_1 \\ y_2 \\ y_3 \\ \cdot \\ \cdot \\ \cdot \\ y_n \end{bmatrix} = 0 \qquad \text{(B-5)}$$

Solution det $|\underline{\lambda}| = 0$ gives eigenvalues of the vibration modes.

$$\lambda_i = \omega_i^2$$

The addition of damping to the model requires the addition of a damper force at each node.

$$F_{DP} = -V_p * B_p \text{ (see Figure B-2)} \tag{B-6}$$

where

B_p = Damping constant of point P
V_p = Velocity of point P

so equation (B-4) becomes:

$$\frac{d^2 y_p}{dt^2} = \frac{-T}{m_p \ell_{p-1}} (y_p - y_{p-1}) + \frac{T}{m_p \ell_p} (y_{p+1} - y_p) - \frac{B \dot{y}_p}{m_p} \tag{B-7}$$

where

$$\frac{d}{dt}(y_p) = \dot{y}_p$$

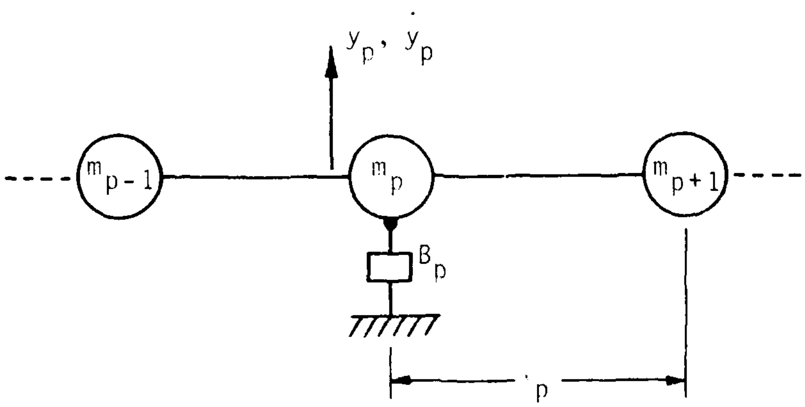


Figure B-2. Nodal dampers (lateral).

The matrix formulation (B-5) becomes (using $\ell_p = \ell_{p-1}$ assumption):

$$\begin{bmatrix} \ddot{y}_1 \\ \dot{y}_1 \\ \ddot{y}_2 \\ \dot{y}_2 \\ \ddot{y}_3 \\ \dot{y}_3 \\ \cdot \\ \cdot \\ \cdot \\ \ddot{y}_n \\ \dot{y}_n \end{bmatrix} + \begin{bmatrix} \frac{B}{m_1},\ 2\lambda_i,\ 0,\ -\lambda_i,\ 0\ldots \\ 1,\ 0,\ldots \\ 0,\ -\lambda_2,\ \frac{B}{m_2},\ 2\lambda_2,\ 0,\ -\lambda_2,\ 0\ldots \\ 0,\ 0,\ 1,\ 0\ldots \\ 0,\ 0,\ 0,\ -\lambda_3,\ \frac{B}{m_3},\ 2\lambda_3,\ 0,\ -\lambda_3,\ 0\ldots \\ 0,\ 0,\ 0,\ 0,\ 1,\ 0,\ldots \\ \cdot \\ \cdot \\ \cdot \\ 0\ldots \qquad\qquad 0,\ -\lambda_n,\ \frac{-B}{m_n},\ 2\lambda_n \\ 0\ldots \qquad\qquad\qquad 0,\ 1,\ 0 \end{bmatrix} * \begin{bmatrix} \dot{y}_1 \\ y_1 \\ \dot{y}_2 \\ y_2 \\ \dot{y}_3 \\ y_3 \\ \cdot \\ \cdot \\ \cdot \\ \dot{y}_n \\ y_n \end{bmatrix} \qquad \text{(B-8)}$$

Solution of det $|\lambda| = 0$ gives the eigenvalues (natural frequencies) of the vibration modes.

B.2.2 Longitudinal Vibration Model

In Figure B-3 the force due to displacement X_i is:

$$F_i = -K_i X_i - K_{i+1} X_i + K_{i+1} X_{i+1} + K_i X_{i-1} \quad \text{(B-9)}$$

$$F_i = -(K_i + K_{i+1}) X_i + K_{i+1} X_{i+1} + K_i X_{i-1} \quad \text{(B-10)}$$

From,

$$\bar{F} = \bar{M}A$$

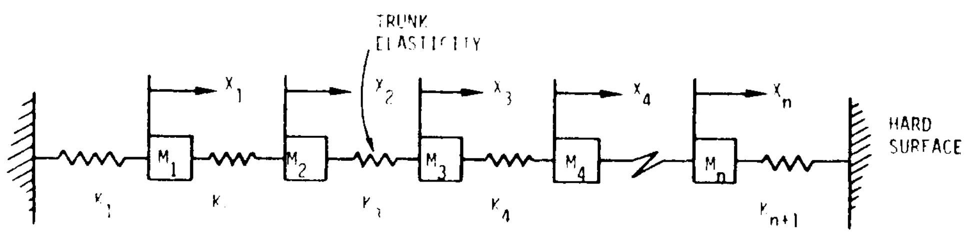


Figure B-3. Longitudinal vibration model.

$$F_i = m_i \frac{d^2X_i}{dt^2} \qquad \text{(B-11)}$$

therefore,

$$\frac{d^2X_i}{dt^2} - \frac{K_i}{m_i} X_{i-1} - \frac{K_{i+1}}{m_i} X_{i+1}$$

$$+ \left(\frac{K_i + K_{i+1}}{m_i}\right) x_i = 0 \qquad \text{(B-12)}$$

where boundary conditions are

$$X_o = X_{n+1} = 0$$

In matrix form:

$$\ddot{\underline{X}} + \underline{\lambda}\ \underline{X} = 0$$

$$\underline{\lambda} = \underline{M}^{-1}\underline{K}$$

$$
\begin{bmatrix} \ddot{X}_1 \\ \ddot{X}_2 \\ \ddot{X}_3 \\ \cdot \\ \cdot \\ \cdot \\ \ddot{X}_n \end{bmatrix}
+
\begin{bmatrix}
\frac{(K_1 + K_2)}{m_1}, & \frac{-K_2}{m_1}, & 0 \ldots & & \\
\frac{-K_2}{m_2}, & \frac{(K_2 + K_3)}{m_2}, & \frac{-K_3}{m_3}, & 0 \ldots & \\
0, & \frac{-K_3}{m_3}, & \frac{(K_3 + K_4)}{m_3}, & \frac{-K_4}{m_4} & . \\
 & & \cdot & & \\
 & & \cdot & & \\
 & & \cdot & & \\
0 \ldots \frac{-K_n}{m_n}, & & & \frac{(K_n + K_{n+1})}{m_n} &
\end{bmatrix}
*
\begin{bmatrix} X_1 \\ X_2 \\ X_3 \\ \cdot \\ \cdot \\ \cdot \\ X_n \end{bmatrix}
= 0 \qquad \text{(B-13)}
$$

Solution of det $|\underline{\lambda}| = 0$ gives the eigenvalues of the vibration modes.

$$\lambda_i = \omega_i^2$$

Addition of damping to the model requires the addition of a damper force at each node.

$$F_{Di} = -V_i * B_i \qquad \text{(B-14)}$$

(see Figure B-4).

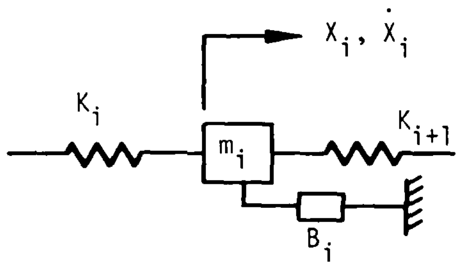


Figure B-4. Nodal dampers (longitudinal).

Equation (B-12) becomes

$$\frac{d^2 X_i}{dt^2} - \frac{K_i}{m_i} X_{i-1} - \frac{K_{i+1}}{m_i} X_{i+1} \left(\frac{K_i + K_{i+1}}{m_i} \right) X_i$$

$$+ \frac{B_i}{m_i} \dot{X}_i = 0 \tag{B-15}$$

In matrix form:

$$\begin{bmatrix} \ddot{X}_1 \\ \dot{X}_1 \\ \ddot{X}_2 \\ \dot{X}_2 \\ \cdot \\ \cdot \\ \cdot \\ \ddot{X}_n \\ \dot{X}_n \end{bmatrix} + \begin{bmatrix} \frac{B_1}{m_1}, \frac{(K_1 + K_2)}{m_1}, 0, \frac{-K_2}{m_1}, 0\ldots \\ 1, 0,\ldots \\ 0, \frac{-K_2}{m_2}, \frac{+B_2}{m_2}, \frac{(K_2 + K_3)}{m_2}, 0, \frac{-K_3}{m_2}, 0,\ldots \\ 0, 0, 1, 0,\ldots \\ \\ \\ \\ 0,\ldots \quad 0, \frac{-K_n}{m_n}, \frac{B_n}{m_n}, \frac{(K_n + K_{n+1})}{m_n} \\ 0,\ldots \quad 0, 1, 0 \end{bmatrix} * \begin{bmatrix} \dot{X}_1 \\ X_1 \\ \dot{X}_2 \\ X_2 \\ \cdot \\ \cdot \\ \cdot \\ \dot{X}_n \\ X_n \end{bmatrix} \quad \text{(B-16)}$$

B.2.3 Coupled Longitudinal and Lateral Motion

The two dimensional matrix formulation requires a two coordinate vector (X_n, Y_n) at each node creating a 2*NODES state space. The matrix formulation of the model requires linearization of the equations about some configuration of the membrane. Each spring element has its linear stiffness matrix converted to the global coordinate frame as shown in Figure B-5.

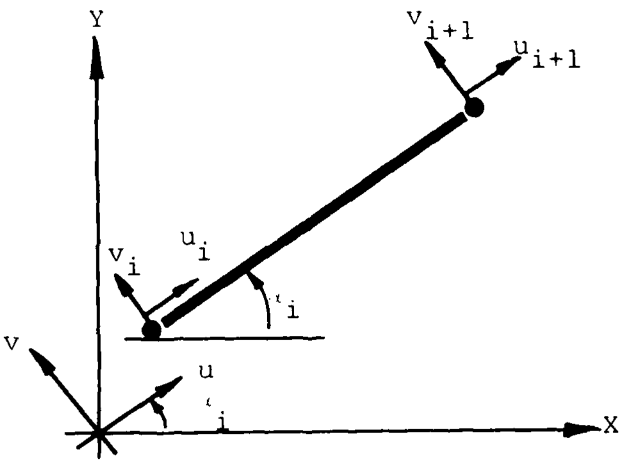


Figure B-5. Element coordinate transformation.

Stiffness of an element

$$\underline{K} = \int_{\ell} \underline{B}^T \underline{K}\underline{B}\, d\ell$$

$$\underline{K} = K_c \begin{bmatrix} 1 & -1 \\ -1 & 1 \end{bmatrix} \quad \text{in one dimension}$$

$$\bar{K}_i = \left[\begin{array}{cc|cc} \cos^2\alpha & \sin\alpha\cos\alpha & -\cos^2\alpha & -\sin\alpha\cos\alpha \\ \sin\alpha\cos\alpha & \sin^2\alpha & -\sin\alpha\cos\alpha & -\sin^2\alpha \\ \hline -\cos^2\alpha & -\sin\alpha\cos\alpha & \cos^2\alpha & \sin\alpha\cos\alpha \\ -\sin\alpha\cos\alpha & -\sin^2\alpha & \sin\alpha\cos\alpha & \sin^2\alpha \end{array}\right] \begin{Bmatrix} u_i \\ v_i \\ u_\eta \\ v_\eta \end{Bmatrix}$$

in two dimensions

$$\underline{R} = [K]_i \{\delta\}_i$$

$$\underline{U}^T = \left[U_1 V_1 \; U_2 V_2\right]$$

$$\underline{K} = \sum_{1}^{N+1} \underline{K}_i \quad ; \quad \underline{KU} = \underline{R} \tag{B-17}$$

$\underline{K}$ = global stiffness matrix

$\underline{U}$ = displacement vector

$\underline{R}$ = forcing load vector.

The membrane tension stiffness effects must be added to the element spring stiffness matrix. The computation of the two dimensional equivalent stiffness for tensile forces requires a linearization of transverse nodal motion into the second coordinate frame.

From lateral one dimensional development earlier, effective lateral stiffness due to tension:

$$\hat{k} = \frac{T*2}{(\ell_i + \ell_{i-1})} \quad \text{in Figure B-6} \tag{B-18}$$

since

$$\hat{k} * \cos(\hat{\alpha}) \approx \hat{k}_y$$

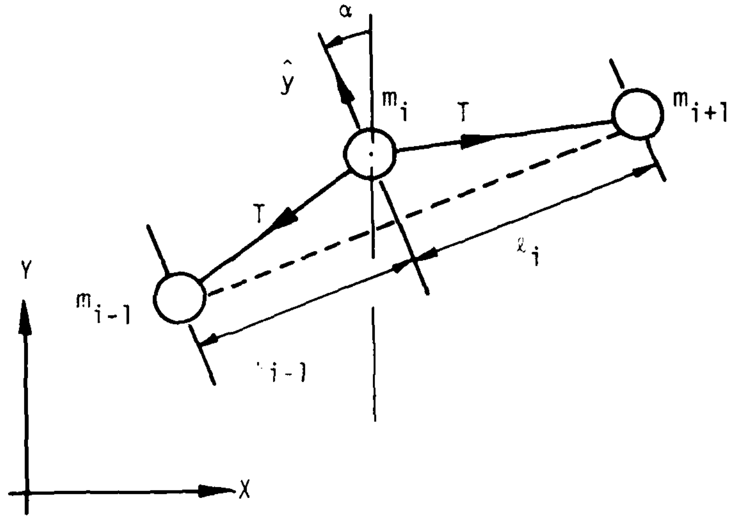


Figure B-6. Transverse node displacement.

$$\hat{k} * \sin(\hat{\alpha}) \approx k_x$$

with

$$\hat{\alpha}_i = \left(\frac{\alpha_i + \alpha_{i-1}}{2}\right) ; \quad \ell_a = \frac{\ell_i + \ell_{i-1}}{2}$$

then

$$F_T = \frac{-T}{\ell_a} (\hat{y}_i - \hat{y}_{i-1}) + \frac{T}{\ell_a} (\hat{y}_{i+1} - \hat{y}_i)$$

or

$$F_T = \hat{K}(\hat{y}_{i+1} - 2\hat{y}_i + \hat{y}_{i-1}) \quad \text{(B-19)}$$

($\hat{y}$ is rotated relative to y by α.)

The lateral $\hat{y}$ displacement must be transformed into (X,Y) frame as follows

Transverse displacement D transformation into (X,Y) frame

$$\Delta y \cos(\hat{\alpha}_i) + \Delta x \sin(\hat{\alpha}_i) = D \quad \text{(Figure B-7)} \quad \text{(B-20)}$$

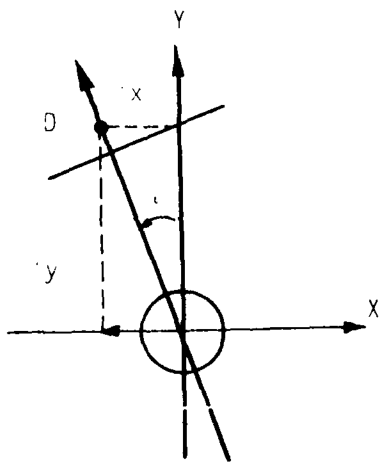


Figure B-7. Force transformation.

$$\hat{y}_i = y_i \left[\cos\ (\hat{\alpha}_i)\right] + x_i \left[\sin\ (\hat{\alpha}_i)\right]$$

$$F_{X_i} = \frac{T}{\ell_a} \sin \hat{\alpha}_i \left| \overbrace{\left[\sin \hat{\alpha}_{i-1}\ x_{i-1} + \cos \hat{\alpha}_{i-1}\ y_{i-1}\right]}^{\hat{y}_{i-1}} \right. \quad \text{(B-21)}$$

$$\left. -2(\hat{y}_i) + \hat{y}_{i+1} \right|$$

$$F_{Y_i} = \frac{T}{\ell_a} \cos \hat{\alpha}_i \left[\hat{y}_{i-1} - 2\hat{y}_i + \hat{y}_{i+1}\right] \quad \text{(B-22)}$$

B.3 Eigenvalue Input Data

1. ICNTL(I), I = 1, 10 IPRNT(I), I = 1, 10 (20I1)

Program Control vectors

				Values
ICNTL (N)	=	1, Eigenvalues; 2, Eigenvectors; 0, skip		
N	=	(1)	;	compute two-dimensional Eigenvalues
N	=	(2)	;	compute two-dimensional damped Eigenvalues
N	=	(3)	;	compute transverse string undamped Eigenvalues
N	=	(4)	;	compute transverse damped Eigenvalues
N	=	(5)	;	compute longitudinal bar undamped Eigenvalues
N	=	(6)	;	compute longitudinal bar damped Eigenvalues

IPRNT N = 1, print matrix as above; 0, No print

2. NODES (I2)

NODES - Number of nodes

3. LS, RL, AX, BX, TENSN, HY (8G10.5)

LS - membrane length, stretched
RL - membrane length, unstretched
AX - horizontal distance between attachment point
BX - vertical distance between attachment point
TENSN - membrane preload tension
HY - trunk height

4. MASS(I), I = 1, nodes (8G10.5)

MASS - lumped parameter nodal mass

5. RKVEC(I), I = 1, nodes + 1 (8G10.5)

RKVEC - elastic stiffness of element

6. DAMP(I), I = 1, nodes (8G10.5)

DAMP - nodal damping in both x and y directions

7. IXF (20I1)

IXF - element length select flag
(0, default; 1, read card 8)

8. (Option) RLENGO(I), I = 1, nodes + 1 (8G10.5)

RLENGO - element unstretched length

9. IXY (20I1)

IXY - coordinate point select flag
(0, read cards 10, 11; 1, compute)

10. (Option) X(I), I = 1, nodes (8G10.5)

X - X values of mass nodes

11. (Option) Y(I), I = 1, nodes (8G10.5)

Y - Y values of mass nodes.

B.4 Eigenvalue Program Output

The printout includes the following data:

a. Input Parameters - Trunk parameters, structural parameters, and program control data are printed out after input. A sample input is shown in Figure B-8.

b. Matrix Model Data (Optional) - The matrices generated for the models can be printed out. These matrices are the global stiffness matrices of the algebraic models for the trunk.

c. Eigenvalues - The Eigenvalues and natural frequencies of the matrix models are printed out in radian and Hertz frequencies, respectively.

d. Eigenvectors (Optional) - The Eigenvectors for each Eigenvalue of complex pair of Eigenvalues are printed and then the normalized displacement Eigenvectors (velocity terms for damped models are neglected) are printed.

CARD NO.

```
1 ———   101010000010101[illegible]
2 ———   16
3 ———   9.75      12.0      4.725     1.272     940.5     2.955
4 ———   1.0135,1.0135,0.506757,0.506757,0.506757,0.506757,0.506757,0.506757
        0.506757,0.506757,0.506757,0.506757,0.506757,0.506757,1.0135,1.0135
5 ———   3926.0    3926.0    3926.0    3926.0    3926.0    3926.0    3926.0    3926.0
        3926.0    3926.0    3926.0    3926.0    3926.0    3926.0    3926.0    3926.0
        3926.0
6 ———   0.010     0.010     0.010     0.010     0.010     0.010     0.010     0.010
        0.010     0.010     0.010     0.010     0.010     0.010     0.010     0.010
7 ———   1
8 ———   0.887272  0.887272  0.443636  0.443636  0.443636  0.443636  0.443636  0.443636
        0.443636  0.443636  0.443636  0.443636  0.443636  0.443636  0.443636  0.887272
        0.887272
9 ———   0
10 ———  0.13570   0.690     1.1196    1.582     2.0711    2.5603    3.1022    3.6285
        4.1501    4.6451    5.0918    5.4731    5.7762    5.9915    6.1391    5.6379
11 ———  0.9615    1.7605    2.0631    2.3131    2.5060    2.6377    2.7044    2.7023
        2.6299    2.4486    2.1678    1.6024    1.3692    0.8857    -0.0822   -0.9229
```

Figure B-8. Sample input data.

A list of program output variables in sequential order is:

1. Number of nodes, NODES

2. Membrane length, LS; rest length, RL, X end point, AX; Y end point, BX; membrane tension, TENSN

3. Mass Modes, MASS(I)

4. Elastic stiffness, RKVEC(I)

5. Damping ratio (global) at node, DAMP(I)

6. Membrane element unstretched length, RLENGO

7. Node coordinate positions, X(I), Y(I)

8. Continuous string frequencies, W(I)

9. 2D stiffness matrix, G(I,J) (Option)

10. Eigenvectors of matrix, Z, W(I), Y(I), Hertz, radians/sec, eigenvalue (real, imaginary)

11. Eigenvectors, X(I), Y(I) eigenvector (real, imaginary) (Option)

12. Eigenvectors, X(I), normalized displacement terms only (Option)

13. 2D damped stiffness matrix, A(I,J) (Option)

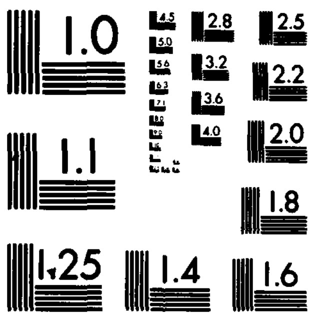
14. As 10 above, eigenvalue

15. As 11 above, eigenvector

AD-A082 087 FOSTER-MILLER ASSOCIATES INC WALTHAM MASS F/G 1/3
ANALYSIS OF TRUNK FLUTTER IN AN AIR CUSHION LANDING SYSTEM. USE--ETC(U)
NOV 79 R B FISH F33615-78-C-3412
UNCLASSIFIED AFFDL-TR-79-3121 NL

2 of 2

END
DATE
FILMED
4-80
DTIC



MICROCOPY RESOLUTION TEST CHART

16. As 12 above, normalized eigenvector

17. 1D lateral stiffness matrix, GS(I,J) (Option)

18. As 10 above, eigenvalue

19. As 11 above, eigenvector

20. As 12 above, normalized eigenvector

21. 1D damped lateral stiffness matrix, XW(I,J) (Option)

22. As 10 above, eigenvalues

23. As 11 above, eigenvectors

24. As 12 above, normalized eigenvectors

25. 1D longitudinal stiffness matrix, GS(I,J) (Option)

26. As 10 above, eigenvalues

27. As 11 above, eigenvectors

28. As 12 above, normalized eigenvectors

29. 1D damped longitudinal stiffness matrix, XW(I,J) (Option)

30. As 10 above, eigenvalues

31. As 11 above, eigenvectors

32. As 12 above, normalized eigenvectors.

Figure B-9 shows a sample program output.

```
NODES = 16

LENGTH        LENGTH IC     A POINT      B POINT      TENSION      HZ
9.75          12.0          4.75         1.2720       940.53       2.9506

MASS NODES
3.15 06E-02 3.15 06E-02 1.57505E-02 1.57505E-02 1.57505E-02 1.57505E-02 1.57505E-02 1.57505E-02 1.57505E-02 1.57505E-02
1.57505E-02 1.57505E-02 1.57505E-02 1.57505E-02 3.15006E-02 3.15006E-02

SPRING COEFFICIENTS
 4424.8      4424.8      8849.6      8849.6      8849.6      8849.6      8849.6      8849.6      8849.6      8849.6
 8849.6      8849.6      8849.6      8849.6      8849.6      4424.8      4424.8

NODE DAMPING
 .23612      .23612      .23612      .23612      .23612      .23612      .23612      .23612      .23612      .23612
 .23612      .23612      .23612      .23612      .33393      .23612

LENGTH
 .88727      .88727      .44364      .44364      .44364      .44364      .44364      .44364      .44364      .44364
 .44364      .44364      .44364      .44364      .44364      .88727      .88727


 NODE POSITIONS
 X          Y

0.000      0.0000
 .1357      .9615
 .6900     1.7635
1.1196     2.0931
1.5820     2.3131
2. 711     2.5060
2.5803     2.6377
3.1022     2.7044
3.6285     2.7023
4.1561     2.6299
4.6451     2.4486
5. 918     2.1678
5.4731     1.8024
5.7762     1.3692
5.3915      .8857
6.1391     -.1822
5.6379     -.9229
4.7250    -1.2720


CONTINUOUS STRING FREQUENCIES HZ

 7.8867
 15.773
 23. 60
 31. 47
 39. 34
 47. 2
```

Figure B-9. Sample output data.

```
[illegible]
[illegible]
[illegible]
78.967
86.75.
94.[illegible]
1[illegible].53
113.41
114.30
126.12

[illegible] DAMPED MATRIX

-[illegible].165[illegible]E+03 1.351[illegible]E+03  [illegible]       [illegible]        0.           0.           0.           0.           0.           0.
 .            0.           0.           0.           0.           0.           0.           0.           0.           0.
 .            0.           0.           0.           0.           0.           0.           0.           0.           0.
 .            0.

-[illegible]E+03 2.[illegible]735E+03 [illegible]       1.02297E+03  0.           0.           0.           0.           0.           0.
 .            0.           0.           0.           0.           0.           0.           0.           0.           0.
 .            0.           0.           0.           0.           0.           0.           0.           0.           0.
 .            0.

 [illegible]     [illegible]       -2.[illegible]E+05-2.37660E+05 2.03430E+05 1.57537E+05 0.           0.           0.           0.
 .            0.           0.           0.           0.           0.           0.           0.           0.           0.
 .            0.           0.           0.           0.           0.           0.           0.           0.           0.
 .            0.

 [illegible]  1.04518E+03-2.37660E+05-2.23369E+05 1.46947E+05 1.15736E+05 0.           0.           0.           0.
 .            0.           0.           0.           0.           0.           0.           0.           0.           0.
 .            0.           0.           0.           0.           0.           0.           0.           0.           0.
 .            0.

 .            0.           4.[illegible]165E+05 3.04379E+05-8.73334E+05-6.01313E+05 4.60023E+05 2.89309E+05 0.           0.
 .            0.           0.           0.           0.           0.           0.           0.           0.           0.
 .            0.           0.           0.           0.           0.           0.           0.           0.           0.
 .            0.

 .            0.           3.36556E+05 2.58660E+05-6.01313E+05-4.77620E+05 2.75821E+05 2.14651E+05 0.           0.
 .            0.           0.           0.           0.           0.           0.           0.           0.           0.
 .            0.           0.           0.           0.           0.           0.           0.           0.           0.
 .            0.

 .            0.           0.           0.           4.60815E+05 2.75810E+05-9.61455E+05-5.13741E+05 5.01050E+05 2.37351E+05
 .            0.           0.           0.           0.           0.           0.           0.           0.           0.
 .            0.           0.           0.           0.           0.           0.           0.           0.           0.
 .            0.

 .            0.           0.           0.           2.89593E+05 2.14627E+05-5.13741E+05-3.89435E+05 2.23609E+05 1.73561E+05
 .            0.           0.           0.           0.           0.           0.           0.           0.           0.
 .            0.           0.           0.           0.           0.           0.           0.           0.           0.
 .            0.
```

Figure B-9. Sample output data. (Continued)

B.5 Principal Nomenclature

Program Variable Name	Symbol	Explanation
A, XW, XZ(I,J)		Matrix, global stiffness
AS, G, GS(I,J)		Matrix, global stiffness
AT, WORKM, XT(I,J)		Matrix, global stiffness
AX	a	Horizontal distance between attachment points
BX	b	Vertical distance between attachment points
COSALP(I)	$\cos(\theta_i)$	Cosine of ALPHA(I)
COSTHE(I)	$\cos(\theta_i)$	Cosine of THETA(I)
DAMP(I)	D_i	Damping ratio of node (I)
ESTIF(I,J)		Matrix, element stiffness
EVEC(I)		Work vector space
ICNTL(I)		Program control vector
IPRNT(I)		Printer control vector
IXF		Flag, element initial length selection
IXY		Flag, X, Y position selection
LS	ℓ_s	Trunk length
L1	ℓ_1	Trunk inner length
L2	ℓ_2	Trunk outer length
MASS(I)	m_i	Nodal mass
NODES		Number of nodes
PHI1	ϕ_1	Trunk angle, inner
PHI2	ϕ_2	Trunk angle, outer

Program Variable Name	Symbol	Explanation
R1	R_1	Trunk radius, inner
R2	R_2	Trunk radius, outer
RKVEC(I)	RK_i	Trunk elasticity, element (I)
RL		
RLENG(I)	RL_i	Trunk element length (I)
RLENGO(I)	RL_{0i}	Trunk element initial length (I)
SINALP(I)	$\sin(\theta_i)$	Sine of ALPHA(I)
SINTHE(I)	$\sin(\theta_i)$	Sine of THETA(I)
TENSN	T	Tension in trunk
W	ω	String frequency
WORK1(I)		Matrix, work space
WORK2(I)		Matrix, work space
X(I)	X_i	X position of node (I)
Y(I)	Y_i	Y position of node (I)

APPENDIX C

PRINCIPLE PROGRAM NOMENCLATURE

The variables used in the flutter simulation program are defined in this appendix. Also mentioned, corresponding to the appropriate computer program variables, are the symbols used in the analysis of the trunk model. All program variables are in ft-lb-sec units except where indicated to the contrary.

Program Variable Name	Symbol	Explanation
A	a	Horizontal distance between inner and outer trunk attachment point
AGAP(I)	A_i	Flow gap trunk to ground
AIFAN	I_f	Fan inertance
ATC	A_{tc}	Area trunk to cushion
ATCF(I)	A_{tcf_i}	Area trunk to cushion element
ATRIM	A_{tr}	Area trim valve
B	b	Vertical distance between inner and outer trunk attachment point
CGAP	C_g	Discharge coefficient gap flow
CKK		Polytropic expansion coefficient
COSPHI(I)	$\mathrm{Cos}(\phi_i)$	Cosine of PHI (I)
COSTHE(I)	$\mathrm{Cos}(\theta_i)$	Sine of THETA (I)
CQ0	α_0	Fan polynomial coefficient 1
CQ1	α_1	Fan polynomial coefficient 2
CQ2	α_2	Fan polynomial coefficient 3
CQ3	α_3	Fan polynomial coefficient 4
CQ4	α_4	Fan polynomial coefficient 5

Program Variable Name	Symbol	Explanation
CTC	C_{tc}	Discharge coefficient trunk to cushion, flow other than trim.
CTRIM	C_{tr}	Discharge coefficient trim value
DAMP(I)	D_i	Damping ratio X, Y at node (I)
DAMPR		Damper rest value
DERY(I)	$\frac{d}{dt}(S_i)$	Derivatives of state variables
DQ	dq	Incremental flow trunk-channel
DTIME	dt	Integration time step
DVCH	$\frac{d}{dt}(V_{ch})$	Cushion volume rate of change
DW(I)	dw_i	Incremental mass flow trunk - channel element (I)
FORCXB(I)	F_{xb_i}	Force, X direction, bending (I)
FORCXD(I)	F_{xd_i}	Force, X direction, damping (I)
FORCXK(I)	F_{xk_i}	Force, X direction, elasticity (I)
FORCXP(I)	F_{xp_i}	Force, X direction, pressure (I)
FORCYB(I)	F_{yb_i}	Force, Y direction, bending (I)
FORCYD(I)	F_{yd_i}	Force, Y direction, damping (I)
FORCYK(I)	F_{yk_i}	Force, Y direction, elasticity (I)
FORCYP(I)	F_{yp_i}	Force, Y direction, pressure (I)
GAPMIN		Minimum gap area
HY		Trunk height
ICFLAG		Flag, trunk shape selection

Program Variable Name	Symbol	Explanation
ICNTL(I)		Control vector for options
ICS		Cushion separation node
IFSEP		Flag, separation point selection
ILENG		Flag, segment length selection
INODE		Node number of lowest trunk point
INSEP		Stake location node
ISEP		Separation point node
L	ℓ	Trunk membrane length
L1	ℓ_1	Inner trunk length (inner attachment point to bottom)
L2	ℓ_2	Outer trunk length (outer attachment point to bottom) (ℓ_1, ℓ_2 used only by subroutine TRUNK)
NODES		Number of mass nodes
PAT	P_a	Atmospheric pressure
PCH	P_{ch}	Cushion pressure
PCRIT		Critical flow pressure
PEXT(I)		External pressure on trunk
PHI(I)	ϕ_i	Angle PHI at node (I)
PLOST		Pressure loss due to momentum
PRESUR(I)		Pressure differential on trunk element
PTK	P_{tk}	Trunk pressure
QCA	Q_{CA}	Flow, cushion to atmosphere
QEXIT	Q_{EXIT}	Flow at exit (separation)
QFAN	Q_{FAN}	Fan flow
QGAP	Q_{GAP}	Gap flow
QIN	Q_{IN}	Flow to trunk

Program Variable Name	Symbol	Explanation
QINT		Momentum change integral
QOUT	Q_{out}	Flow, out of trunk
QTA	Q_{TA}	Flow, trunk to atmosphere
QTC	Q_{TC}	Flow, trunk to cushion
QTOT		Total gap flow
QTRIM	Q_{TR}	Flow, trim valve
RBVEC(I)	RB_i	Bending stiffness, node (I)
RHO	ρ	Air density
RITER		Iteration parameter
RKEXTX		External spring stiffness, X
RKEXTY		External spring stiffness, Y
RKVEC(I)	RK_i	Trunk elasticity
RLENG(I)	RL_i	Trunk element length
RLENGO(I)	RL_{0_i}	Trunk element unstretched length
RMASS(I)	M_i	Nodal mass
SIE(I)	Ψ_i	Angle SIE
SINPHI(I)	$SIN(\phi_i)$	Sine of PHI(I)
SINTHE(I)	$SIN(\theta_i)$	Sine of THETA(I)
SSLENG		Trunk gap length
STATE(I)	S_i	State variable (I)
TEMPAT		Atmospheric temperature
THETA(I)	θ_i	Angle THETA(I)
TIME	t	Simulation time
TKVOL	V_{tk}	Trunk volume
TREST		Damper reset time

Program Variable Name	Symbol	Explanation
TSEP		Separation point angle
VCH	V_{ch}	Volume of cushion
VEL(I)	V_i	Velocity of flow at node (I)
VEXIT	V_{exit}	Initial estimate of flow velocity at separation point
VSEP	V_s	Velocity at separation point
W(I)	W_i	Mass flow at node (I)
X(I)	X_i	X position of node (I)
XEXTO		X position of spring at rest
XZETA	ξ_x	X damping ratio
Y(I)	Y_i	Y position of node (I)
YASEP	Y_s	Flow separation point area
YCSEP		Cushion separation point area
YDMIN		Minimum trunk Y displacement
YEXTO		Y position of spring at rest
YGAPM		Minimum gap area
YGRNDS		Hard surface clearance
YSEPX		Separation point gap

APPENDIX D

PROGRAM LISTINGS

All programs and subroutines in this report have been designed to work under ANSI.66 FORTRAN IV and supersets of the former.

- Dynamic Program Listings (subsection D.1)
- Eigenvalue Program Listings (subsection D.2)

NOTE

Subroutines HSBG, and ATEIG have been omitted. Information on these routines can be found in the IBM SSP manual.

D.1 Dynamic Simulation Programs

The following programs and subroutines are included.

Programs - DYSYS

Subroutines - RKDIF
EQSIM
TRUNK
PUTVEC
ERROR
PLOTTER
PACKER
PRNTPLOT
PLOT
PSTORE

```
      PROGRAM DYSYS(INPUT,OUTPUT,TAPE5=INPUT,TAPE6=OUTPUT,TAPE4)
C *****
C ***** FOSTER MILLER ASSOCIATES
C ***** ANALYSIS AND INSTRUMENTATION GROUP
C ***** 350 SECOND AVE
C ***** WALTHAM,MASS. 02154
C ***** (617) 890-3200
C ***** COPYRIGHT 1979
C *****
      REAL YMIN(100),YMAX(100)
      DIMENSION IPRNT(9),YPRNT(9)
      COMMON T,TSTEP,Y(100),F(100),STIME,FTIME,NEWDT,IFWRT,N,
     1 IPR,ICD,ICN,TNEXT,PNEXT,TRACK
      COMMON/PLOT/NPLT(10),TPLSRT,TPLSTP,NPLTN,DTPLOT,XPLOTX(5,200)
     1 ,NDIM,NVPLOT,XMIN,XMAX,NPMAX,NSTORE
      COMMON/IOLIST/NTYP,NINP,IPTAPE
C
C NTYP = OUTPUT DEVICE CHANNEL
C NINP = INPUT DEVICE CHANNEL
C
C NEWDT IS NON-ZERO IF IT IS OK TO CHANGE DT (OR SCALING)
C
C FORMATS
1     FORMAT(3G12.5)
2     FORMAT(8G10.0)
3     FORMAT(1P,10G12.4)
 4    FORMAT(1P,6X,*MAXIMUM ORDER OF SYSTEM=*,I3,6X,*INITIAL TIME=*,
     1G11.4, 3X,*FINAL TIME=*,G11.4,6X,*TIME STEP=*,G12.5)
6     FORMAT (1H1 6X*SOLUTION OF STATE EQUATIONS USING DYSYS*//)
7     FORMAT (9I2)
 8    FORMAT(//15X,9(A1,*STATE*,6X))
 9    FORMAT(16X,9(A1,*(*,I2,*)*,7X))
 12   FORMAT(5X,*TIME*,5X,9(A1,*VARIABLE*,3X))
14    FORMAT(6X,*Y(*,I2,*) *,1P,2G18.4)
 15   FORMAT(/*0EXTREME VALUES OF STATE AND AUXILIARY VARIABLES*/
     1 T24,*MINIMUM*,T42,*MAXIMUM*)
C
```

```
C SET UP DEVICE NUMBERS
      NTYP=6
      NINP=5
      IPTAPE=4
      ICD=NINP
      IPR=NTYP
      N=100
C
C INPUT INTEGRATION CONTROL PARAMETERS
100   READ(NINP,1) FTIME,TSTEP,STIME
110   WRITE (IPR,6)
      WRITE (IPR,4) N,STIME,FTIME,TSTEP
      IFWRT=0
C SET STATES OUT OF BOUNDS
      DO 120 I=1,N
      YMIN(I)=1.7E50
      YMAX(I)=-1.7E50
      F(I)=0.0
120   Y(I)=0.0
C
C FIND PRINTING VECTOR LENGTH.
      READ (ICD,7) IPRNT
      READ(NINP,7) NPLTV
      DO 130 I=1,9
      IF (IPRNT(I)) 140,140,130
130   CONTINUE
      I=10
140   NPRNT=I-1
C
C ON FIRST CALL TO EOSIM, NEWDT IS NEGATIVE
      NEWDT=-1
      T=STIME
C
C CALL EOSIM FOR INITIALIZATION OF SYSTEM
      CALL EOSIM
      T=STIME
300    CONTINUE
       IF (N.LT.0) GO TO 100
```

```
C USE Y(N+1) THROUGH Y(NMAX) AS AUXILIARY STORAGE SPACE
      IPR1=2
      IF(NPRNT)410,410,310
310   IPR1=1
      WRITE (IPR,8) (IB,I=1,NPRNT)
      WRITE (IPR,12) (IB,I=1,NPRNT)
      WRITE (IPR,9) (IB,IPRNT(I),I=1,NPRNT)
      WRITE (IPR,2)
C PRINT RESULTS
320    GO TO (340,410),IPR1
340   DO 350 I=1,NPRNT
      L=IPRNT(I)
350   YPRNT(I)=Y(L)
      WRITE (IPR,3) T,(YPRNT(I),I=1,NPRNT)
C SAVE MAXIMUM AND MINIMUM
410   DO 450 I=1,N
      IF (Y(I)-YMIN(I)) 420,430,430
420   YMIN(I)=Y(I)
430   IF (Y(I)-YMAX(I)) 450,450,440
440   YMAX(I)=Y(I)
450   CONTINUE
C TEST FOR COMPLETE
C GET OUT IF T IS NOT BETWEEN STIME AND FTIME
      TX=T+0.5*TSTEP
      IF((STIME-TX)*(FTIME-TX))460,480,480
C CALL INTEGRATION ROUTINE FOR TIME STEP
 460  CALL RKDIF
      GO TO 320
 480  IF(NPRNT.LE.0) GO TO 520
C
C WRITE OUT MAXIMUM AND MINIMUM OF VARIABLE IF IT WAS USED
      WRITE(IPR,15)
      DO 510 I=1,N
      IF(YMIN(I))500,490,500
 490  IF(YMAX(I))500,510,500
 500  WRITE(IPR,14)I,YMIN(I),YMAX(I)
510   CONTINUE
C
```

```
C IF PLOTTING DONE CALL OUTPUT ROUTINES
520   IF(NPLT4.GE.1) CALL PLOTTER
600   WRITE(NTYP,9010)
9010  FORMAT(5X,18H END OF DYSYS JOB  ,/)
      END
```

```
      SUBROUTINE RKDIF
C RUNGE-KUTTA 4TH ORDER INTEGRATION ROUTINE
C
      REAL SY(100),Y0(100),Y1(100),Y2(100)
      COMMON T,TSTEP,Y(100),DY(100),STIME,FTIME,NEWDT,IFWRT,N,
     1 IPR,ICD,ICN,TNEXT,PNEXT,TBACK
      EQUIVALENCE (DT,TSTEP),(N,NSYS)
C
C NEWDT IS NON-ZERO IF IT IS OK TO CHANGE TIME STEPS
C SET NEWDT TO LOCK OUT CHANGES IN DT AND INPUTS
C
      NEWDT=0
      H=DT/2.0
      DO 10 I=1,NSYS
      SY(I)=Y(I)
      Y0(I)=DY(I)
 10   Y(I)=H*DY(I)+Y(I)
C
      T=T+H
      CALL EQSIM
C
      DO 20 I=1,NSYS
      Y1(I)=DY(I)
 20   Y(I)=SY(I)+H*DY(I)
C
      CALL EQSIM
C
      DO 30 I=1,NSYS
      Y2(I)=DY(I)
 30   Y(I)=SY(I)+DT*DY(I)
C
      T=T+H
      CALL EQSIM
      H=H/3.0
C
      DO 40 I=1,NSYS
      PRT1=2.0*(Y1(I)+Y2(I))
      PRT2=Y0(I)+DY(I)
```

```
      Y(I)=SY(I)+H*PRT1+H*PRT2
40    CONTINUE
C SET NEWDT = -1 FOR END OF STEP
      NEWDT=1
      CALL EQSIM
      RETURN
      END
```

```
      SUBROUTINE EQSIM
C DYSYS DYNAMIC INTEGRATION STATE EQUATION SUBROUTINE
C
C ***********************************************************
C
C DYSYS STATE EQUATIONS FOR ACLS TRUNK
C LUMPED PARAMETER MEMBRANE MODEL
C
C UNITS ARE IN FT,SLUG,SECOND SYSTEM
C
C NODES 1 AND NUMBER+2 ARE FIXED BOUNDARY POINTS
C FOR I=5,NUMBER OF NODES+1,4
C STATE(I) = X(I) VELOCITY
C STATE(I+1) = X(I) POSITION
C STATE(I+2) = Y(I) VELOCITY
C STATE(I+3) = Y(I) POSITION
C
C FORCE COMPONENT VECTOR(X,Y)
C FORCXD,FORCYD = DAMPER FORCE COMPONENTS
C FORCXK,FORCYK = SPRING FORCE COMPONENTS
C FORCXP,FORCYP = PRESSURE FORCE COMPONENTS
C FORCXB,FORCYB = BENDING FORCE COMPONENTS
C
C ************************************************************
C
C *****
C ***** FOSTER MILLER ASSOCIATES
C ***** ANALYSIS AND INSTRUMENTATION GROUP
C ***** 350 SECOND AVE
C ***** WALTHAM,MASS. 02154
C ***** (617) 890-3200
C ***** COPYRIGHT 1979
C *****
C
      REAL L,L1,L2
      INTEGER*2 XLAB
C
      LOGICAL LDATS(16)
```

```
C
      DIMENSION RLENG(42),RLENGO(42)
      DIMENSION RLENGO(42)
      DIMENSION RMASS(40),RKVEC(42)
      DIMENSION DAMP(42),X(48),Y(48)
      DIMENSION PRESUR(42)
      DIMENSION SINTHE(42),COSTHE(42)
      DIMENSION COSPHI(42),SINPHI(42)
      DIMENSION FORCXP(42),FORCYP(42)
      DIMENSION FORCXK(42),FORCYK(42)
      DIMENSION FORCXD(42),FORCYD(42)
      DIMENSION PEXT(42),AGAP(44)
      DIMENSION RKFACT(5)
      DIMENSION RKSAV(42),RLSAV(42)
      DIMENSION THETA(42)
      DIMENSION ICNTL(16)
      DIMENSION PHI(42),STE(42),RBVEC(42)
      DIMENSION FORCXB(42),FORCYB(42)
      DIMENSION XLAB(40),FORCXG(42),FORCYG(42)
      DIMENSION W(42),VEL(42)
      DIMENSION ATCF(42)
      DIMENSION DW(42)
C
      COMMON TIME,DTIME,STATE(100),DERY(100),STIME,FTIME,NEWDT,IFWRT,N,
     1 IPR,ICD,ICN,TNEXT,PNEXT,TRACK
      COMMON/GEOMET/A,B,HYI,L,HY,PHI1,PHI2,R1,R2,L1,L2,TSHAPE
      COMMON/IOLIST/NTYP,NINP,IPTAPE
      COMMON/PLOT/NPLT(10),TPLSRT,TPLSTP,NPLTM,DTPLOT,XPLOTX(5,200)
     1 ,NDIM,NVPLOT,XMIN,XMAX,NPMAX,NSTORE
C
      EQUIVALENCE (TX,THX)
      EQUIVALENCE (RLENGO(1),RLENGO(1))
      EQUIVALENCE(QEXIT,QOUT)
      EQUIVALENCE(CDGAP,CGAP)
C
C ORIFICE FLOW EQUATION
      QFLOW(X,Y)=X*SQRT(ABS(Y))*SIGN(STIRHO,Y)
C
```

```
C FAN DYNAMICS PRESSURE VS. FLOW EQUATION
      PFANX(Q)=C00+C01*Q+C02*Q*Q+C03*Q**3+C04*Q**4
C
C ********************************************************************
C
C EOSIM ENTRY POINT
C
C ********************************************************************
C
C NEWDT = -1 ON FIRST CALL  =1 ON 4TH CALL PER TIME STEP ELSE 0
      IF(NEWDT)1,2,2
C
C INPUT INITIAL DATA
CALLED FOR SIMULATION SET UP ONCE
1     CONTINUE
      NSMAX=100
      NSTORE=100
      NMAX=40
      NMAX1=41
      NMAX2=NMAX*2
      PI=3.141592
      YDMIN=5.0
      G=32.174
      PCTOT=0.0
      RNUM=0.0
      DVCH=0.0
      CKK=1.4
      PAT=14.7*144.0
      TEMPAT=70.0
      RHO=1.241/(460.0+TEMPAT)
      STIRHO=SQRT(2.0/RHO)
      QTC=0.0
      QTRIM=0.0
      QCA=0.0
      QFAN=0.0
C CLEAR VECTORS TO ZERO FOR STATE AND DERIVATIVES
      DERY(I)=0.0
      DO 10 I=1,NSMAX
```

```
      STATE(I)=0.0
10    CONTINUE
C
      DO 15 I=1,NMAX1
      PEXT(I)=0.0
      FORCXD(I)=0.0
      FORCYD(I)=0.0
      FORCXK(I)=0.0
      FORCYK(I)=0.0
      FORCXP(I)=0.0
      FORCYP(I)=0.0
      FORCXB(I)=0.0
      FORCYB(I)=0.0
      FORCXG(I)=0.0
      FORCYG(I)=0.0
      PRESUR(I)=0.0
      RLENG(I)=0.0
15    CONTINUE
C
C READ JOB LABEL CARD
      READ(NINP,9430)(XLAB(I),I=1,40)
9430  FORMAT(40A2)
      WRITE(NTYP,9431)(XLAB(I),I=1,40)
9431  FORMAT(/,5X,40A2,/)
C
C INPUT CONTROL VECTOR
C ICNTL(1) ON = 1 FOR CUSHION PRESSURE DYNAMICS
C ICNTL(2) ON = 1 FOR TRUNK-FAN PRESSURE DYNAMICS
C ICNTL(3) ON = 1 FOR TRUNK FLOW INTO CHANNEL
C ICNTL(4) ON = 1 FOR SEPARATION POINT INTERPOLATION
C ICNTL(5) ON = 1 FOR SPECIAL NO TRUNK MOTION EXECUTION
C ICNTL(6) ON = 1 FOR STATIC PRESSURE LOAD CASE
C
      READ(NINP,9006)(ICNTL(I),I=1,16)
9006  FORMAT(80I1)
      WRITE(NTYP,9432)(ICNTL(I),I=1,16)
9432  FORMAT(5X,16I3,/)
      DO 12 I=1,16
```

```
      LDATS(I)=.FALSE.
      IF(ICNTL(I).GT.0) LDATS(I)=.TRUE.
12    CONTINUE
C LIST OPTIONS IN EFFECT
      WRITE(NTYP,9440)
9440  FORMAT(5X,*OPTIONS IN EFFECT =*)
      IF(LDATS(1)) WRITE(NTYP,9441)
9441  FORMAT(10X,*DYNAMIC CUSHION PRESSURE*)
      IF(LDATS(2)) WRITE(NTYP,9442)
9442  FORMAT(10X,*DYNAMIC TRUNK-FAN PRESSURE*)
      IF(LDATS(3)) WRITE(NTYP,9443)
9443  FORMAT(10X,*TRUNK TO CHANNEL FLOW*)
      IF(LDATS(4)) WRITE(NTYP,9444)
9444  FORMAT(10X,*SEPARATION POINT INTERPOLATION*)
      IF(LDATS(5)) WRITE(NTYP,9445)
9445  FORMAT(10X,*NO TRUNK MOTION TEST RUN*)
      IF(LDATS(6)) WRITE(NTYP,9446)
9446  FORMAT(10X,*STATIC PRESSURE LOAD CASE*)
C
C INPUT NUMBER OF MASS NODES FOR ANALYSIS
C ICFLAG = 0 FOR READ X,Y ELSE COMPUTE
C IFXN = PRINT AND PLOTTER VS STEP NUMBER
C IFSEP = SEPARATION POINT SELECTION FLAG =2 FOR DIFFUSER ELSE 1
C ILENG = ELEMENT LENGTH CONTROL FLAG
C INSEP = SEPARATION POINT NODE SET
C
      READ(NINP,9005) NODES,ICFLAG,IFXN,IFSEP
     1,ILENG,INSEP
9005  FORMAT(10I5)
      NODES1=NODES+1
      NODES2=NODES+2
      NSTATE=NODES2*4
      N=NODES2*4+ICNTL(1)+ICNTL(2)*2
      WRITE(NTYP,9402)
9402  FORMAT(/,5X,31H NODES,NSTATE,ICFLAG,IFXN,IFSEP ,12H INSEP,ILENG  )
      WRITE(NTYP,9120) NODES,NSTATE,ICFLAG,IFXN,IFSEP
     1,INSEP,ILENG
9120  FORMAT(10I10,/)
```

```
C
C GEOMETRY CONSTANTS
      READ(NINP,9000)A,B,L,HYI
      HY=HYI
      WRITE(NTYP,9401)
9401   FORMAT(5X,11H A,B,L,HYI )
      WRITE(NTYP,9110)A,B,L,HY
C
      READ(NINP,9000)SSLENG,TPERIM
      WRITE(NTYP,9421)
9421  FORMAT(5X,* SSLENG,TPERIM *)
      WRITE(NTYP,9110)SSLENG,TPERIM
      READ(NINP,9000) ATC,ATRIM
      WRITE(NTYP,9428)
      WRITE(NTYP,9110) ATC,ATRIM
9428  FORMAT(5X,* ATC,ATRIM *)
      READ(NINP,9000)(ATCF(I),I=1,NODES1)
      WRITE(NTYP,9425)
9425  FORMAT(/,5X,* AREA TRUNK-GAP EACH ELEMENT *)
      CALL PUTVEC(ATCF,NODES1)
C
C ILENG , 1=READ DATA CARDS , 0= COMPUTE L/NODES
      IF(ILENG)7,7,8
8     READ(NINP,9000)(RLENGO(I),I=1,NODES1)
      GO TO 9
7     DO 6 I=1,NODES1
      RLENGO(I)=L/FLOAT(NODES1)
6     CONTINUE
9     CONTINUE
      WRITE(NTYP,9408)
9408  FORMAT(5X,11H SPRING L 0   )
      CALL PUTVEC(RLENGO,NODES1)
C
C SET BOUNDARY NODES
      X(1)=0.0
      Y(1)=0.0
      Y(NODES2)=-B
      X(NODES2)=A
```

```
C
C OPTION TO USE TRUNK MODEL
      IF(ICFLAG)16,16,25
C
C INPUT NODE COORDINATES
16    READ(NINP,9000)(X(I),I=2,NODES1)
      READ(NINP,9000)(Y(I),I=2,NODES1)
9000  FORMAT(8G10.4)
      GO TO 45
C
C OPTIONAL TRUNK SHAPE INITIAL CONDITIONS
C ONLY GOOD FOR EQUISPACED NODES
25    CALL TRUNK
      NX=IFIX(FLOAT(NODES)*(PHI2*R2/L))
      NZ=NODES-NX
      WRITE(NTYP,9120)NX,NZ
C
C COMPUTE RIGHT SECTOR POINTS
      XCNTR=R2*SIN(PHI2)
      YCNTR=HY-R1
      TX=2.0*ASIN(RLENGO(1)*0.5/R1)
      ANG=ATAN2((X(NODES2)-XCNTR),(Y(NODES2)-YCNTR))
      DO 40 I=1,NZ
      ANG=ANG-TX
      J=NODES2-I
      X(J)=XCNTR+R1*SIN(ANG)
      Y(J)=YCNTR+R1*COS(ANG)
40    CONTINUE
C
C COMPUTE LEFT SECTOR POINTS
      YCNTR=YCNTR+R1-R2
      ANG=1.570796-PHI2
      TX=2.0*ASIN(RLENGO(1)*0.5/R2)
      DO 43 I=1,NX
      ANG=ANG+TX
      J=I+1
      X(J)=XCNTR-R2*COS(ANG)
      Y(J)=YCNTR+R2*SIN(ANG)
```

```
43     CONTINUE
C
C FORCE NODES ABOVE GROUND LEVEL
45     DO 46 I=1,NODES2
       Y(I)=AMIN1(YOMIN,Y(I))
46     CONTINUE
        WRITE(NTYP,9010)
9010   FORMAT(//,5X,15H NODE POSITIONS,/,2X,2H X,10X,2H Y ,/)
C LOAD STATE VECTOR X,Y WITH INPUT DATA
       DO 20 I=1,NODES2
       J=(I-1)*4+2
       STATE(J)=X(I)
       STATE(J+2)=Y(I)
        WRITE(NTYP,9020)  X(I),Y(I)
9020   FORMAT(2(2X,F8.4))
20     CONTINUE
       WRITE(NTYP,9414)
9414   FORMAT(/)
C
C COMPUTE THETA NODE ANGLES
       DO 21 I=1,NODES1
21     THETA(I)=ATAN2((Y(I+1)-Y(I)),(X(I+1)-X(I)))
       IFLAG=IFXN
       WRITE(NTYP,9409)
9409   FORMAT(5X,12H NODE ANGLES  )
       CALL PUTVEC(THETA,NODES1)
C
C INPUT MASS IN POUNDS
       READ(NINP,9000)(RMASS(I),I=1,NODES)
C CHANGE MASS TO SLUGS
       DO 5 I=1,NODES
       RMASS(I)=RMASS(I)/G
5      CONTINUE
22     WRITE(NTYP,9405)
9405   FORMAT(5X,12H NODE MASSES  )
       CALL PUTVEC(RMASS,NODES)
C
C INPUT MEMBRANE STIFFNESS LB/FT
```

```
      READ(NINP,9000)(RKVEC(I),I=1,NODES1)
C SAVE SPRING DATA
      DO 4 I=1,NODES1
      RKSAV(I)=RKVEC(I)
4     CONTINUE
      WRITE(NTYP,9406)
9406  FORMAT(5X,17H SPRING CONSTANTS  )
      CALL PUTVEC(RKVEC,NODES1)
C
C
C INPUT MEMBRANE BENDING STIFFNESS LB/RAD
      READ(NINP,9000)(RBVEC(I),I=1,NODES)
      WRITE(NTYP,9415)
9415  FORMAT(5X,18H BENDING STIFFNESS  )
      CALL PUTVEC(RBVEC,NODES)
C
C INPUT MEMBRANE DAMPING LB-SEC/FT
      READ(NINP,9000)(DAMP(I),I=1,NODES)
      WRITE(NTYP,9407)
9407  FORMAT(5X,13H NODE DAMPING  )
      CALL PUTVEC(DAMP,NODES)
C
C DAMPER RESET TIME AND FACTOR
      ITR=0
      READ(NINP,9000)TREST,DAMPR
      WRITE(NTYP,9429)
9429  FORMAT(5X,* TREST,DAMPR *)
      WRITE(NTYP,9110) TREST,DAMPR
C
C INPUT EXTERNAL STIFFNESS COEFFICIENTS
      READ(NINP,9001) IEXT,RKEXTX,RKEXTY
9001  FORMAT(I2,2G10.5)
C
C SAVE I.C. FOR SPRING ATTACHMENT
      XEXTO=X(IEXT)
      YEXTO=Y(IEXT)
      IF(IEXT .NE. 0) WRITE(NTYP,9002) IEXT,RKEXTX,RKEXTY
9002  FORMAT(5X,25H EXTERNAL SPRING AT NODE ,I2,5H RKX=,
```

```
     1 F12.5,5H RKY=,F12.5,/)
C
C INPUT FLUID CONTROL PARAMETERS
      READ (NINP,9000) AIFAN,TKVOL,VCH
      WRITE(NTYP,9426)
9426  FORMAT(5X,* AIFAN,TKVOL,VCH *)
      WRITE(NTYP,9110) AIFAN,TKVOL,VCH
C FAN POLYNOMIAL COEFFICIENTS
      READ(NINP,8901) C00,C01,C02,C03,C04
      WRITE(NTYP,9427)
9427  FORMAT(5X,*C00,C01,C02,C03,C04 *)
      WRITE(NTYP,8902) C00,C01,C02,C03,C04
8901  FORMAT(5F15.5)
8902  FORMAT(5X,6(G13.6,2X))
      READ(NINP,9000)CTC,CTRIM,CGAP,TSEP
      WRITE(NTYP,9420)
9420  FORMAT(5X,* CTC,CTRIM,CGAP,TSEP *)
      WRITE(NTYP,9110)CTC,CTRIM,CGAP,TSEP
      READ(NINP,9000) YGRNDS,SRATIO,YDMIN
      WRITE(NTYP,9403)
9403  FORMAT(5X,* YGRNDS,SRATIO,YDMIN*)
      WRITE(NTYP,9110) YGRNDS,SRATIO,YDMIN
C
      READ(NINP,9000)PTK,PCH,QGAP
C IF DYNAMIC FAN SET INITIAL CONDITION
      IF(LDATS(1)) STATE(N)=PCH
      IF(LDATS(2)) STATE(N-1)=PTK
      IF(LDATS(2)) STATE(N-2)=QGAP
      IF(LDATS(2)) QFAN=QGAP
C SET EQUILIBRIUM FLOW INPUT AS FUNCTION OF PCH AND GAP
      QIN=0.0
      QEXIT=0.0
C IF DYNAMIC CUSHION PRESSURE SET I.C.
      IF(LDATS(1)) STATE(N)=PCH
      WRITE(NTYP,9404)
9404  FORMAT(5X,* PTK,PCH,QGAP *)
      WRITE(NTYP,9110)PTK,PCH,QGAP
9110  FORMAT(5X,10F12.5,/)
```

```
C
      IF(.NOT.LOATS(6)) GO TO 2
C INPUT OUTER PRESSURE PROFILE
      READ(NINP,9000)(PEXT(I),I=1,NODES)
      WRITE(NTYP,9410)
9410  FORMAT(5X,18H NODE EXT PRESSURE  )
      CALL PUTVEC(PEXT,NODES1)
C
C ***************************************************************************
C
C ONE ENTRY PER STEP
C
C ***************************************************************************
C
C LIMIT Y NODE DISPLACMENT TO GROUND
2     DO 2500 I=1,NODES
      J=I*4+2
      STATE(J+2)=AMIN1(STATE(J+2),YDMIN)
2500  CONTINUE
C TEST IF LAST CALL FOR STEP ,ELSE GOTO 3
      IF(NEWDT)30,3,30
C
C *****
30    YMAX=0.0
C FIND LOWEST NODE POINT ON TRUNK
      DO 5000 I=2,NODES1
      IF(Y(I).LT.YMAX) GO TO 5000
      INODE=I
      YMAX=Y(I)
5000  CONTINUE
C
C INODE= NUM OF MIN GAP NODE
C COMPUTE GAP AREAS
5001  DO 5005 I=1,NODES2
      AGAP(I)=AMAX1(0.0,(YGRNDS-Y(I)))
5005  CONTINUE
      ICS=1
      YCSEP=AGAP(1)
```

```
C GAP AT LOWEST POINT
      YGAPM=AGAP(INODE)
C IF LDATS(6) TRUE STATIC PRESSURE INPUT,SKIP DYNAMICS
      IF(LDATS(6)) GO TO 5081
C
C IF NO GAP JUMP TO SPECIAL NO FLOW CASE
      IF(YGAPM.EQ.0.0) GO TO 5054
      YC=YGAPM*10.0
C LOOK BACK TO FIND CUSHION SEPARATION POINT
      DO 5010 I=1,INODE
      IF(AGAP(I).LT.YC) GO TO 5020
C REMEMBER POINT
      ICS=I
      YCSEP=AGAP(I)
5010  CONTINUE
C
C *****************************************************************
C SEPARATION POINT SELECTION ROUTINE
5020  ISEP=INODE
      YASEP=AGAP(ISEP)
C IFSEP .EQ. 1 FOR FIXED GAP CASE
C IFSEP .EQ. 2 FOR DIFFUSER CASE
C IFSEP .EQ. 3 FOR SET TO NODE = INSEP
C IF TRUNK TO GAP FLOW SET SEPARATION POINT
      GO TO (5021,5031,5035),IFSEP
C
C *****
C SET SEPARATION GAP BY INPUT VALUE
C PICK FIRST NODE WITH GAP EQUAL TO YSEPX
5021  YSEPX=YGAPM/SRATIO
      DO 5030 I=INODE,NODES2
      IF(AGAP(I).LT.YSEPX) GO TO 5030
      ISEP=I
C Y AT SEPARATION POINT = YSEPX VALUE = YGAPM/SRATIO
      YASEP=AMIN1(YSEPX,AGAP(I))
      GO TO 5051
5030  CONTINUE
      CALL ERROR(1)
```

```
C
C *****
C SEPARATION POINT FROM DIFFUSER MODEL
C 6 DEGREE SLOPE OR MORE FOR SEPARATION
C LOOK FROM LOWEST NODE OUTWARD
5031  ISEP=INODE
      YASEP=AGAP(ISEP)
      DO 5040 I=ISEP,NODES2
      IF(THETA(I).GT.TSEP) GO TO 5040
      GO TO 5041
5040  CONTINUE
      CALL ERROR(2)
      YASEP=AGAP(I)
      GO TO 5050
C
C *****
C FORCE SEPARATION POINT TO BE AT NODE INSEP
5035  ISEP=INSEP
      YASEP=AGAP(ISEP)
      GO TO 5051
C
C *****
C INTERPOLATION SCHEME FOR SEPARATION POINT GAP
5050  IF(.NOT.LDATS(4)) GO TO 6200
      TEMP1=TSEP-THETA(ISEP)
      TEMP2=THETA(ISEP)-THETA(ISEP+1)
      TEMP1=(AGAP(ISEP+1)-AGAP(ISEP))*(TEMP1/TEMP2)
      YASEP=AGAP(ISEP)-TEMP1
      GO TO 5051
C
C *****
C TRUNK FLOW SET SEPARATION POINT
6200  IF(.NOT.LDATS(3)) GO TO 5051
C LOOK FOR SEPARATION POINT
      DO 6210 I=1,NODES1
      J=NODES2-I
      ISX=J
      IF(ATCF(J).GT.0.0) GO TO 6250
```

```
6210  CONTINUE
      CALL ERROR(3)
6250  IF(ISX.GE.ISEP) GO TO 5051
      ISEP=ISX
      YASEP=AGAP(ISEP)
C
C *****
C PRESSURE = PCH FOR NODES 1 TO ICS
C PRESSURE = PAT FOR NODES ISEP+1 TO NMAX
C PRESSURE = F(VEL) FOR NODES ICS+1 TO ISEP
C MINIMUM GAP FLOW AREA AT NODE = INODE
C
5051  ICS1=ICS+1
      ISEP1=ISEP+1
      ICS1=MINO(ICS1,NODES2)
      ISEP1=MINO(ISEP1,NODES2)
C
C COMPUTE VELOCITY AND FLOW AT EXIT POINT
C USE SEPARATION GAP TO CONTROL TOTAL FLOW Q=CA*F(P)
      VEXIT=SQRT(2.0*PCH/RHO)
      QEXIT=VEXIT*YASEP
      GO TO 5055
C
C *****
C SPECIAL NO FLOW CASE
5054  CONTINUE
      QEXIT=0.0
      ICS=INODE
      ISEP1=INODE+1
C
C *****
C LOAD OUTER PRESSURE DATA ARRAY
C LOAD CUSHION PRESSURE FROM INNER EDGE TO CUSHION SEPARATION
5055  DO 5060 I=1,ICS
      PEXT(I)=PCH
5060  CONTINUE
C
C LOAD ATMOSPHERE PRESSURE FROM SEPARATION POINT TO END
```

```
      DO 5070 I=ISEP1,NODES2
      PEXT(I)=0.0
5070   CONTINUE
C IF NO FLOW PATH VECTOR OUT
      IF(QEXIT.EQ.0.0) GO TO 5081
C
C *****
C FROM VELOCITY AT EACH POINT DETERMINE PRESSURE
C USE BERNOULLI IDEAL FLOW RELATION EQUATION
C COMPUTE MINIMUM PRESSURE DUE TO FLOW
      PCRIT=(PCH+2116.8)*0.528-2116.8
      DO 5080 I=ICS1,ISEP
      PEXT(I)=PCH*(1.0-(YASEP/AGAP(I))**2)
      PEXT(I)=AMAX1(PEXT(I),PCRIT)
5080  CONTINUE
C
      IF(.NOT.LDATS(3)) GO TO 5081
C *****
C TRUNK TO GAP FLOW EFFECT COMPUTATION
C
C TRUNK TO CHANNEL COMPUTATION ROUTINE
C MASS FLOW AT CUSHION SEPARATION POINT
      DO 6010 I=1,NODES2
      VEL(I)=0.0
      W(I)=0.0
      DW(I)=0.0
6010  CONTINUE
C INITIAL MASS FLOW
      ATMP=0.0
      ITCNT=0
      DO 6100 I=1,NODES1
      ATMP=ATMP+ATCF(I)
6100  CONTINUE
C ESTIMATE TRUNK FLOW INTO CHANNEL
      QEST=ATMP*CTC*SQRT(2.0/RHO*(PTK-PCH*0.5))*0.90
      VSEP=QEST/YASEP
C PRESSURE DROP ESTIMATE DUE TO MOMENTUM
      PLOST=VSEP*RHO/YASEP*QEST
```

```
C INITIAL MASS OUT OF CUSHION
      W(1)=RHO*CTC*YASEP*SQRT(2.0/RHO*AMAX1(0.0,(PCH-PLOST)))
      RITER=0.10
C
C USING ESTIMATE OF CUSHION PRESSURE FLOW ITERATE PROFILE
6015  QINT=0.0
      QTOT=W(1)/RHO
      DO 6050 I=2,ISEP
      DQ=0.0
      DW(I)=0.0
      IF(ATCF(I).EQ.0.0) GO TO 6040
C USE PRESSURE AT I-1 AND ESTIMATE OF P(I)
      PAVE=(PEXT(I)+PEXT(I-1))*0.5
C COMPUTE FLOW INTO CONTROL VOLUME FROM TRUNK
      DQ=QFLOW(CTC,(PTK-PAVE))*ATCF(I)
      DW(I)=DQ*RHO
C COMPUTE MASS FLOW AT EXIT OF CONTROL VOLUME
6040  QTOT=QTOT+DQ
      VEL(I)=QTOT/AGAP(I)
      W(I)=DW(I)+W(I-1)
C COMPUTE MOMENTUM CHANGE PRESSURE DROP
      QINT=1.0/AGAP(I)*VEL(I)*DW(I)+QINT
C COMPUTE NEW ESTIMATE OF NODE PRESSURE
      PEXT(I)=PCH-0.5*RHO*VEL(I)**2-QINT
      PEXT(I)=AMAX1(PEXT(I),PCRIT)
6050  CONTINUE
C
C TEST IF EXIT POINT PRESSURE IS WITHIN BOUNDS SET
      IF((PEXT(ISEP).GT.-1.0).AND.(PEXT(ISEP).LT.1.0)) GOTO 6075
C ERROR ON EXIT PRESSURE ,ITERATE
      ITCNT=ITCNT+1
C ALLOW ONLY TEN ITERATIONS ON PRESSURE
      IF(ITCNT.GE.11) GOTO 6075
      IF(ITCNT.GE.5) RITER=RITER*0.90
C CORRECT INITIAL FLOW FROM CUSHION TO ZERO P EXIT
      W(1)=W(1)+CTC*RITER*RHO*QFLOW(YASEP,PEXT(ISEP))
      GO TO 6015
6075   CONTINUE
```

```
C
C *****
C IF NODE CONTACT SET TO TRUNK PRESSURE
5081  DO 5082 I=2,NODES1
      IF(AGAP(I).LE.0.0) PEXT(I)=PTK
5082  CONTINUE
5090  CONTINUE
C
C NOW HAVE PRESSURE PROFILE FOR TRUNK
      DO 75 I=1,NODES1
      PRESUR(I)=PTK-PEXT(I)
75    CONTINUE
C
C *****
C DATA SWITCH 2 ON FOR TRUNK-FAN DYNAMICS
      IF(.NOT.LDATS(2)) GO TO 1480
      QFAN=STATE(N-2)
      QFAN=AMIN1(QFAN,3000.0)
      PTK=STATE(N-1)
      PTK=AMAX1(PTK,0.0)
C
C COMPUTE DYNAMIC CUSHION PRESSURE RELATIONS
C DATA SWITCH 1 MUST BE .TRUE. FOR DYNAMIC CUSHION PRESSURE
1480  IF(.NOT.LDATS(1)) GO TO 1490
C COMPUTE TOTAL FLOW FROM CUSHION
      AGAPX=YASEP*2.0*SSLENG
      PCH=STATE(N)
      PCH=AMAX1(PCH,0.0)
      QTA=0.0
      QCA=AGAPX*QFLOW(CGAP,PCH)
      QTC=ATC*QFLOW(CTC,(PTK-PCH))
      QTRIM=ATRIM*QFLOW(CTRIM,(PTK-PCH))
C TRUNK TO CHANNEL FLOW
      IF(.NOT.LDATS(3)) GO TO 1490
      QTC=0.0
      QTA=(QTOT-W(1)/RHO)*TPERIM
      QCA=W(1)/RHO*2.0*SSLENG
C
```

```
C *****************************************************************
C SAVE AUXILIARY VARIABLES IF ANY
C SAVE TOTAL LENGTH OF TRUNK SEGMENTS
1490  XL=0.0
      DO 1500 I=1,NODES1
      XL=XL+RLENG(I)
1500  CONTINUE
      IF(NEWDT.EQ.-1) XL=L
      IF(.NOT. LDATS(1)) GO TO 1510
C IF DYNAMIC CUSHION PRESSURE SAVE FLOW DATA
      STATE(N+1)=XL
      STATE(N+2)=QTC
      STATE(N+3)=QTRIM
      STATE(N+4)=QCA
      PCTOT=PCTOT+PCH
      RNUM=RNUM+1.0
      PCAVE=PCTOT/RNUM
      STATE(N+5)=PCAVE
      STATE(N+6)=QTOT
      STATE(N+7)=QTA
C
      ISEP1=ISEP+1
C TEST PRINT OUT FLAG
1510  IF(IFXN.NE.IFLAG) GO TO 1650
      WRITE(NTYP,9056)TIME
      WRITE(NTYP,9412)
9412  FORMAT(5X,14H NODE Y VALUES   )
      CALL PUTVEC(Y,NODES2)
      WRITE(NTYP,9413)
9413  FORMAT(5X,* ICS,ISEP,INODE,YASEP,YGAPM,AGAP(ISEP),VEXIT*,
     1 *,QEXIT,PCH,PTK,QFAN*)
      WRITE(NTYP,9055)ICS,ISEP,INODE,YASEP,YGAPM,AGAP(ISEP),
     1VEXIT,QEXIT,PCH,PTK,QFAN
9055  FORMAT(5X,3I5,8F12.5)
      NP1=N+1
      NP7=N+7
      IF(LDATS(1).OR.LDATS(2)) WRITE(NTYP,9050) (STATE(JK),JK=NP1,NP7)
9050   FORMAT(5X,* XL,QTC,QTRIM,QCA,PCAVE,QTOT,QTA*,/,8F15.5)
```

```
C
      WRITE(NTYP,9410)
      CALL PUTVEC(PEXT,NODES2)
9056   FORMAT(5X,*TIME*,F12.5)
      IFLAG=0
1650   IFLAG=IFLAG+1
C *****
C PLOTTING ROUTINE
      IF(NPLTM.GE.1) CALL PSTORE(NODES)
C
C RESET DAMPING RATION IF AT EQUILIBRIUM TIME
C FIRST CALL,TEST TIME FOR RESET/STEP
      IF(TIME.LT.TREST) GO TO 1700
      IF(ITP)1710,1710,1700
1710  DO 1720 I=1,NODES
      DAMP(I)=DAMP(I)*DAMPR
1720  CONTINUE
      ITR=1
1700  CONTINUE
C
C COMPUTE SPRING CONSTANTS
      DO 1800 I=1,NODES1
      RKVEC(I)=RKSAV(I)*(RLENG(I)/RLENGO(I))
1800  CONTINUE
C
C ****************************************************************************
C
C DIFFERENTIAL EQUATIONS
C CALLED FOUR TIMES PER STEP
C
C ***********************************************************************
C
3     CONTINUE
C
C LOAD X,Y VECTORS FROM STATE ARRAY
      DO 150 I=2,NODES1
      J=(I-1)*4+2
      X(I)=STATE(J)
```

```
      Y(I)=STATE(J+2)
150   CONTINUE
C SPECIAL NO MOTION EXECUTION
      DO 160 I=1,N
160    DERY(I)=0.0
      IF(LDATS(5)) GO TO 1013
C
C *****
      DO 50 I=1,NODES1
C COMPUTE SPRING LENGTHS
      RLENG(I)=SQRT((X(I+1)-X(I))**2+(Y(I+1)-Y(I))**2)
C
C COMPUTE PHI ANGLES
      TX=ATAN2((Y(I)-Y(I+1)),(X(I)-X(I+1)))
      PHI(I)=TX
      COSPHI(I)=COS(TX)
      SINPHI(I)=SIN(TX)
C
C COMPUTE THETA ANGLES
      TX=ATAN2((Y(I+1)-Y(I)),(X(I+1)-X(I)))
      THETA(I)=TX
      SINTHE(I)=SIN(TX)
      COSTHE(I)=COS(TX)
50    CONTINUE
C
C IF FIRST CALL COMPUTE BENDING STIFFNESS INITIAL CONDITION
      IF(NEWDT)51,53,53
51    DO 52 I=1,NODES
      SIE(I)=THETA(I+1)-PHI(I)
52    CONTINUE
C
C *****
C COMPUTE FORCES
53    DO 60 I=1,NODES
C FIND SPRING FORCES AT NODE
C RK1,RK2 ARE SPRING FORCE MAGNITUDES FOR 2 ATTACHED SPRINGS,+=TENSILE
C FORCE = SPRING CONSTANT * DELTA LENGTH/LENGTH
      RK1=(RLENG(I)-RLENGO(I))*RKVEC(I)
```

```
      RK1=RK1/RLENGO(I)
      RK2=(RLENG(I+1)-RLENGO(I+1))*RKVEC(I+1)
      RK2=RK2/RLENGO(I)
      FORCXK(I)=RK1*COSPHI(I)+RK2*COSTHE(I+1)
      FORCYK(I)=RK1*SINPHI(I)+RK2*SINTHE(I+1)
C
C FIND DAMPER FORCES AT NODE
      J=I*4+1
C FORCE = 2.0 * ZETA * OMEGA N * VELOCITY
      XZETA=2.0*SQRT(RMASS(I)*RKVEC(I)/RLENGO(I))
      FORCXD(I)=-STATE(J)*DAMP(I)*XZETA
      FORCYD(I)=-STATE(J+2)*DAMP(I)*XZETA
60    CONTINUE
C
C COMPUTE PRESSURE FORCES
C PRESSURE X,Y COMPONENTS,FORCE = P*A ACTING ON LENGTH/2 ON SIDES OF NOD
      DO 125 I=1,NODES
      FORCXP(I)=-PRESUR(I)*0.5*(RLENG(I)*SINTHE(I)+RLENG(I+1)*SINTHE
     1(I+1))
      FORCYP(I)=PRESUR(I)*0.5*(RLENG(I)*COSTHE(I)+RLENG(I+1)*COSTHE
     1(I+1))
125   CONTINUE
C
C ZERO BENDING FORCES
      DO 129 I=1,NODES
      FORCXB(I)=0.0
      FORCYB(I)=0.0
129   CONTINUE
C
C COMPUTE BENDING FORCES
      DO 130 I=1,NODES
      IF(RBVEC(I).EQ.0.0) GO TO 130
C COMPUTE ANGULAR DISPLACEMENT FROM EQUILIBRIUM
      TX=SIE(I)-(THETA(I+1)-PHI(I))
C IF SIE(I) ANGLE INCREASE TORQUE IS NEGATIVE
      TX=TX*RBVEC(I)
C COMPUTE LENGTH NORMALIZATION FACTOR
      RX1=2.0/(RLENG(I)*(RLENG(I)+RLENG(I+1)))
```

```
      RX2=2.0/(RLENG(I+1)*(RLENG(I)+RLENG(I+1)))
C IF FIRST NODE SKIP FORCE AT ATTACHMENT POINT
      IF(I.EQ.1) GO TO 132
C COMPUTE BENDING EQUIVALENT FORCES IN X,Y TERMS
      FORCXB(I-1)=FORCXB(I-1)+RX1*(-TX)*SINTHE(I)
      FORCYB(I-1)=FORCYB(I-1)+RX1*TX*COSTHE(I)
132   FORCXB(I)=FORCXB(I)+RX1*TX*SINTHE(I)+RX2*TX*SINTHE(I+1)
      FORCYB(I)=FORCYB(I)+RX1*(-TX)*COSTHE(I)+RX2*(-TX)*COSTHE(I+1)
C IF LAST NODE SKIP FORCE AT ATTACHMENT POINT
      IF(I.EQ.NODES) GO TO 130
      FORCXB(I+1)=FORCXB(I+1)+RX2*(-TX)*SINTHE(I+1)
      FORCYB(I+1)=FORCYB(I+1)+RX2*TX*COSTHE(I+1)
130   CONTINUE
C
C COMPUTE FORCES DUE TO EXTERNAL STIFFNESS TERMS
      IF(IEXT.EQ.0) GO TO 140
      FORCXG(IEXT)=-RKEXTX*(X(IEXT)-XEXT0)
      FORCYG(IEXT)=-RKEXTY*(Y(IEXT)-YEXT0)
C
C *****
C
C FORM DIFFERENTIAL VECTOR,4 ELEMENTS PER NODE
C NODES 1 AND N+2 ARE FIXED
C
140   DO 1000 I=1,NODES
1001  CONTINUE
      J=I*4+1
C X VELOCITY
      DERY(J)=(FORCXD(I)+FORCXK(I)+FORCXP(I)+FORCXB(I)+FORCXG(I))/RMASS(
     1I)
C X POSITION
      DERY(J+1)=STATE(J)
C Y VELOCITY
      DERY(J+2)=(FORCYD(I)+FORCYK(I)+FORCYP(I)+FORCYB(I)+FORCYG(I))/
     1 RMASS(I)
C Y POSITION
      DERY(J+3)=STATE(J+2)
C
```

```
1000  CONTINUE
C
C CUSHION PRESSURE STATE VARIABLE
1013  IF(.NOT.LOATS(1)) GO TO 1050
      PCH=STATE(N)
      DERY(N)=CKK*(PCH+PAT)/VCH*(QTC+QTRIM-QCA)
C
      IF(.NOT.LOATS(2)) GO TO 1050
       PTK=STATE(N-1)
      QFAN=STATE(N-2)
C TRUNK PRESSURE EQUATION
      DERY(N-1)=CKK/TKVOL*(PTK+PAT)*(QFAN-QTC-QTA-QTRIM)
C
C FAN EQUATION
      DERY(N-2)=(PFANX(QFAN*0.5)-PTK)/AIFAN
C
C *****
C CONSTRAINTS ON MEMBRANE
C CHECK FOR GROUND CONTACT OF TRUNK
1050  DO 2000 I=1,NODES
      J=I*4+2
C TEST FOR CONTACT
      IF(STATE(J+2).LT.YDMIN) GO TO 2000
C FORCE MAXIMUM ON Y DISPLACEMENT
      STATE(J+2)=AMIN1(STATE(J+2),YDMIN)
C GROUND CONTACT ENERGY ABSORPTION
C FORCE ONLY REBOUND
      DERY(J+1)=AMIN1(0.0,DERY(J+1))
      STATE(J+1)=AMIN1(0.0,STATE(J+1))
2000  CONTINUE
C
      RETURN
      END
```

```
      SUBROUTINE TRUNK
C TRUNK SHAPE ITERATION
      REAL L,L1,L2
      COMMON/GEOMET/A,B,HYT,L,HY,PHI1,PHI2,R1,R2,L1,L2,ISHAPE
      DATA RTOL,PI2/0.01,6.28318/
C
      IF(HY)11,11,1
1     R2=SQRT(A*A*0.25+HY*HY)
      BHY=B+HY
      NMAX=100
      DO 10 I=1,NMAX
      PHI2=ABS(ACOS(AMAX1(-1.0,AMIN1(1.0,((R2-HY)/R2)))))
      SINPH2=SIN(PHI2)
      R1=((A-R2*SINPH2)**2+(BHY*BHY))/(BHY+BHY)
      PHI1=ABS(ACOS(AMAX1(-1.0,AMIN1(1.0,((R1-HY-B)/R1)))))
      XS=A-R2*SINPH2
      IF(XS)5,5,6
5     PHI1=PI2-PHI1
6     L2=L-PHI1*R1
      IF(ABS(PHI2).LT.1.0E-2) PHI2=1.0E-2
      R2S=L2/PHI2
      IF(ABS(R2-R2S).LE.RTOL) GO TO 50
      R2=(R2+R2S)*0.5
10    CONTINUE
C
C ERROR RETURN
11    ISHAPE=0
C
C GOOD RETURN
50    L1=L-L2
      ISHAPE=1
      RETURN
      END
```

```
      SUBROUTINE PUTVEC(A,N)
C SUBROUTINE FOR VECTOR OUTPUT
      DIMENSION A(N)
      COMMON/IOLIST/NTYP,NINP,IPTAPE
      WRITE(NTYP,9010)(A(I),I=1,N)
9010  FORMAT(5X,10G12.5)
      WRITE(NTYP,9000)
9000  FORMAT(/)
      RETURN
      END
```

```
      SUBROUTINE ERROR (I)
C SUBROUTINE FOR ERROR HANDLING IN EOSTM
      COMMON/IOLIST/NTYP,NINP,IPTAPE
C ERROR HANDLING ROUTINE FOR EOSTM
      WRITE(NTYP,9000) I
9000  FORMAT(/,5X,20H ***** ERROR CODE = ,I5,/)
      CALL EXIT
      RETURN
      END
```

```
      SUBROUTINE PLOTTER
C PLOTTING CONTROL SUBROUTINE
      DIMENSION IDUM(5)
      COMMON/PLOT/NPLT(10),TPLSRT,TPLSTP,NPLTM,DTPLOT,XPLOTX(5,200)
     1 ,NDIM,NVPLOT,XMIN,XMAX,NPMAX,NSTORE
      COMMON/IOLIST/NTYP,NINP,IPTAPE
C
C MARK END OF PLOT DATA FILE
      ENDFILE IPTAPE
      DO 1000 IJK=1,NPLTM
      WRITE(NTYP,9100)
9100   FORMAT(1H1)
C READ PLOTTER CONTROL CARD
      READ(NINP,9010) NVPLOT,(NPLT(I),I=1,5)
      READ(NINP,9060) TPLSRT,TPLSTP,DTPLOT,XMIN,XMAX
9060  FORMAT(6F12.5)
      DO 1 I=1,5
      IDUM(I)=NPLT(I)
1     CONTINUE
      WRITE(NTYP,1020)(IDUM(I),I=1,5)
1020   FORMAT(5X,21H PLOTS 1-5 = STATES= ,5I4,/)
9010   FORMAT(I1,4X,5I2)
      IF(NVPLOT.EQ.0) GO TO 1000
      IF(NVPLOT.GT.5) NVPLOT=5
C CALL PACKER TO READ REQUESTEE VARIABLES INTO XPLOTX
      CALL PACKER(I)
C
      IF((XMIN.NE.0.0).AND.(XMAX.NE.0.0)) GO TO 100
      XMAX=XPLOTX(1,1)
      XMIN=XPLOTX(1,1)
      DO 10 K=1,NVPLOT
      DO 10 J=1,I
      IF((K.EQ.1).AND.(J.EQ.1)) GO TO 10
C FIND MINIMUM AND MAXIMUM OF DATA
      XMAX=AMAX1(XMAX,XPLOTX(K,J))
10    XMIN=AMIN1(XMIN,XPLOTX(K,J))
      IF(XMAX.EQ.XMIN) XMAX=XMAX+1.0
      XMAXO=XMAX
```

```
      XMAX=XMAX+0.01*(XMAX-XMIN)
      XMIN=XMIN-0.01*(XMAX0-XMIN)
C CALL PRNTPT TO PLOT DATA ON PRINTER.
100   CALL PRNTPT(I)
      XD=(XMAX-XMIN)/100.0
1000  CONTINUE
2000  CONTINUE
      RETURN
      END
```

```
      SUBROUTINE PACKER(I)
C SUBROUTINE TO PICK DATA POINTS FOR PLOT FROM TAPE
C DTPLOT MUST BE INTEGRAL WITH MAX DT
      DIMENSION X(200)
      COMMON/PLOT/NPLT(10),TPLSRT,TPLSTP,NPLTM,DTPLOT,XPLOTX(5,200)
     1 ,NDIM,NVPLOT,XMIN,XMAX,NPMAX,NSTORE
      COMMON/IOLIST/NTYP,NINP,IPTAPE
C REWIND TAPE 4 TO START OF SIMULATION
      REWIND IPTAPE
      TIMOLD=0.0
      ISTOP=0
      I=0
      NPMAX=200
C READ TIME STEP VARIABLES ANS TIME
10    READ(IPTAPE)(X(IJK),IJK=1,NSTORE),XTIME
C IF END OF FILE STOP READING
20    CONTINUE
C IF TIME .LT. PLOT TIME READ NEXT
       IF((XTIME.LT.TPLTSRT)) GO TO 10
C IF TIME .GT. PLOT TIME RETURN
60    IF(XTIME.GT.TPLSTP) RETURN
C IF TIME SINCE LAST POINT EQUAL DTPLOT SAVE
       IF(XTIME.GE.(TIMOLD+DTPLOT)) GO TO 30
      GO TO 10
  100 ISTOP=1
  30  TIMOLD=XTIME
      I=I+1
      DO 50 J=1,NVPLOT
C LOAD APPROPRIATE CURVE WITH DATA
C NPLT(J) CONTAINS STATE NUMBER TO BE PLOTED
      NJ=NPLT(J)
50    XPLOTX(J,I)=-X(NJ)
C IF ARRAY FULL RETURN
      IF((I.LT.NPMAX).AND.(ISTOP.EQ.0)) GO TO 10
      RETURN
      END
```

```
      SUBROUTINE PRNTPT(NPNTS)
C PRINTER PLOT PROGRAM
C
      INTEGER LINE,XFIG,BLANK,DOT,T,CHAR
      INTEGER SOFF
      DIMENSION LINE(120),XFIG(5)
C
      DIMENSION XPLAB(11)
      COMMON/PLOT/NPLT(10),TPLSRT,TPLSTP,NPLTM,DTPLOT,XPLOTX(5,200)
     1 ,NDIM,NCURVE,XMIN,XMAX,NPMAX,NSTORE
      COMMON/IOLIST/NTYP,NINP,IPTAPE
C
C SET PLOT CURVE SYMBOLS
      DATA BLANK,DOT/4H    ,4H.   /
      DATA XFIG/4H*   ,4HX   ,4H+   ,4HO   ,4H$   /
      DATA T/4HT   /
      DATA SOFF/4H-   /
C
C ROUTINE WILL PLOT 1 TO 5 CURVES PER CALL
      DX=(XMAX-XMIN)/100.0
C QUANTIZATION LEVEL OF DEPENDENT AXIS IS RANGE/100
      IF(NCURVE.GT.5) NCURVE=5
      IF(NPNTS.GT.NPMAX) NPNTS=NPMAX
      IF(NPNTS.LE.0) GO TO 300
       IF(NCURVE.LE.0) GO TO 300
      WRITE(NTYP,1005) XMIN,DX,XMAX
1005   FORMAT(5X,9H MINIMUM= ,F10.4,22X,8H DELTA=  ,F10.4,22X,
     1 9H MAXIMUM= ,F10.4,5X,5H TIME,/)
       WRITE(NTYP,1010)
1010   FORMAT(5X,36H CURVE MARKERS=) 1=* 2=X 3=+ 4=O 5=$ ,
     1 12H -=OFF SCALE ,/)
      DO 5 I=1,11
5     XPLAB(I)=XMIN+DX*FLOAT(I-1)*10.0
      WRITE(NTYP,9000)(XPLAB(I),I=1,11)
9000  FORMAT(1X,11G10.3)
C LOAD LINE WITH BLANKS AND SET MARKERS
      DO 10 I=2,101
10    LINE(I)=DOT
```

```
      LINE(1)=I
      LINE(102)=I
C PRINT FIRST MARKER LINE
      WRITE(NTYP,1001)(LINE(I),I=1,102)
1001   FORMAT(5X,102A1,F10.6)
      XTIME=TPLSRT
      DTIME=(TPLSTP-TPLSRT)/FLOAT(NPNTS)*10.0
      IT=9
C PLOT ARRAY OF CURVES
      DO 100 IJK=1,NPNTS
      DO 20 I=2,119
20    LINE(I)=BLANK
C CLEAR LINE TO BLANKS
C SET BOARDER FOR PLOT
      LINE(1)=DOT
      LINE(102)=DOT
C FOR EACH CURVE SET UP LINE
      DO 200 J=1,NCURVE
      VAL=XPLOTX(J,IJK)
      CHAR=XFIG(J)
      KDEX=IFIX((VAL-XMIN+0.5*DX)/DX)+2
      IF(KDEX.GE.2) GO TO 25
      KDEX=2
      CHAR=SOFF
25    IF(KDEX.LE.101)GO TO 26
      KDEX=101
      CHAR=SOFF
C DETERMINE POINTS POSITION IN LINE
26    LINE(KDEX)=CHAR
200   CONTINUE
C PRINT LINE OF PLOT
      IT=IT+1
      IF(IT-10)30,40,30
40     IT=0
C PUT IN ROWS OF DOTS EVERY TEN STEPS
      DO 45 I=12,92,10
      IF(LINE(I).EQ.BLANK) LINE(I)=DOT
45    CONTINUE
```

```
      WRITE(NTYP,1001)(LINE(K),K=1,102),XTIME
      XTIME=XTIME+DTIME
      GO TO 100
30    CONTINUE
      WRITE(NTYP,1001)(LINE(K),K=1,102)
100   CONTINUE
      DO 33 IJK=2,101
33    LINE(IJK)=DOT
      WRITE(NTYP,1001)(LINE(K),K=1,102),TPLSTP
      RETURN
300   WRITE(NTYP,1002)
1002   FORMAT(5X,45H ERROR CONDITION ON PLOT CONTROL NUMBERS          )
      RETURN
      END
```

```
      SUBROUTINE PSTORE(NODES)
      COMMON/IOLIST/NTYP,NINP,IPTAPE
      COMMON/PLOT/NPLT(10),TPLSRT,TPLSTP,NPLTM,DTPLOT,XPLOTX(5,200)
     1 ,NDIM,NVPLOT,XMIN,XMAX,NPMAX,NSTORE
      COMMON TIME,DTIME,STATE(100),DERY(100),STIME,FTIME,NEWDT,IFWRT,N,
     1 IPR,ICD,ICN,TNEXT,PNEXT,THACK
C
C PLOT FILE STORAGE ROUTINE WRITE IPTAPE OF DATA FOR PLOT
      WRITE(IPTAPE)(STATE(I),I=1,NSTORE),TIME
C
      RETURN
      END
```

D.2 Eigenvalue Analysis Program

The following programs and subroutines are included.

Programs - FMAEVEC

Subroutines - TRUNK
MOVE
CMINV (complex version of IBM-SSP MINV)
ELEMK
CLEAR
PUTMAT
PUTEIG
EIGPAC
EVECTR
VECPAC

```
      PROGRAM FMAEVEC(INPUT,OUTPUT,TAPE5=INPUT,TAPE6=OUTPUT)
C
C ***********************************************************************
C
C LUMPED PARAMETER MEMBRANE MODEL
C EIGENVALUE AND EIGENVECTOR ANALYSIS PROGRAM
C
C *****
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C ***** ANALYSIS AND INSTRUMENTATION GROUP
C ***** 350 SECOND AVE
C ***** WALTHAM,MASS. 02154
C ***** (617) 890-3200
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C *****
C UNITS ARE IN FT,SLUG,SECOND SYSTEM
C
C NODES 1 AND NUMBER+2 ARE FIXED BOUNDARY POINTS
C FOR I=2,NUMBER OF NODES+1 MOVABLE
C
C ***********************************************************************
C
      REAL LS,L1,L2
      REAL MASS
      INTEGER EVEC
C
      DIMENSION RLENG(21),RLENGO(21)
       DIMENSION RLENGO(21)
      DIMENSION DAMP(21),X(22),Y(22)
      DIMENSION THETA(21)
      DIMENSION EVEC(100)
      DIMENSION WORK1(40),WORK2(40)
      DIMENSION RKVEC(21)
      DIMENSION MASS(20)
      DIMENSION FSTIF(4,4)
      DIMENSION COSTHE(21),SINTHE(21)
      DIMENSION ICNTL(10)
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      DIMENSION SINALP(40),COSALP(40)
      DIMENSION A(40,40)
      DIMENSION AS(40,40),AT(40,40)
      DIMENSION G(40,40)
      DIMENSION WORKM(40,40)
      DIMENSION XW(40,40)
      DIMENSION XZ(40,40),XT(40,40)
      DIMENSION GS(40,40)
      DIMENSION IPRNT(10)
C
      COMMON/GEOMET/AX,BX,HY,RL,L1,L2,R1,R2,PHI1,PHI2
C
      EQUIVALENCE (RLENGO(1),RLENGO(1))
      EQUIVALENCE (G(1,1),AS(1,1))
      EQUIVALENCE (G(1,1),GS(1,1))
      EQUIVALENCE (WORKM(1,1),AT(1,1))
      EQUIVALENCE (AT(1,1),XT(1,1))
      EQUIVALENCE (XZ(1,1),A(1,1))
      EQUIVALENCE (XW(1,1),A(1,1))
C
C STORAGE EQUIVALENCY MAPPING
C AT = WORKM = XT
C A = XW = XZ
C AS = G = GS
C
C *******************************************************************
C
C INPUT INITIAL DATA
1     CONTINUE
      NIYP=6
      NINP=5
C NMAT IS STORAGE ARRAY LIMIT
      NMAT=40
      NMATV=21
      NUMAX=NMAT/2
      NDMAX=NMAT/4
      PI=3.141592
      PID2=1.570796
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```
      GO=32.174
      WRITE(NTYP,9003)
9003  FORMAT(1H1)
9002  FORMAT(///)
9050  FORMAT(5X,10G12.5)
9001  FORMAT(/)
C
C CLEAR MATRICIES
      CALL CLEAR(MASS,NMAX,1)
      CALL CLEAR(RKVEC,NMAX,1)
      CALL CLEAR(DAMP,NMAX,1)
      CALL CLEAR(RLENGO,NMAX,1)
C
C INPUT CONTROL INFORMATION
      READ(NINP,9015)(ICNTL(I),I=1,10),(IPRNT(J),J=1,10)
9015  FORMAT(20I1)
C
C ICNTL N = 1,EIGENVALUES  2,EIGENVECTORS
C ICNTL 1 = COMPUTE 2 DIMENSIONAL EIGENVALUES
C ICNTL 2 = COMPUTE 2 DIMENSIONAL DAMPED EIGENVALUES
C ICNTL 3 = COMPUTE TRANSVERSE STRING UNDAMPED EIGENVALUES
C ICNTL 4 = COMPUTE TRANSVERSE DAMPED EIGENVALUES
C ICNTL 5 = COMPUTE LONGITUDINAL BAR UNDAMPED EIGENVALUES
C ICNTL 6 = COMPUTE LONGITUDINAL BAR   DAMPED EIGENVALUES
C
C IPRNT = 1 TO PRINT MATRIX AS IN ICNTL
C
C INPUT NUMBER OF MASS NODES FOR ANALYSIS
      READ(NINP,9005) NODES
9005  FORMAT(I2)
      NODES1=NODES+1
      NODES2=NODES+2
      NMAX=NODES*2
      NMAX2=NMAX*2
      WRITE(NTYP,9051) NODES
9051   FORMAT(5X,8H NODES =,I3,/)
      READ (NINP,9000)LS,RL,AX,BX,TENSN
     1,HY
```

```
      WRITE(NTYP,9056)
9056  FORMAT(5X,12H LENGTH 0    ,12H LENGTH IC  ,12H A POINT    ,12H B PO
     1INT       ,12H TENSION     ,3H HY )
      WRITE(NTYP,9050)LS,RL,AX,BX,TENSN
     1,HY
      WRITE(NTYP,9001)
C
C INPUT MASS IN POUNDS
      READ(NINP,9000)(MASS(I),I=1,NODES)
C INPUT MEMBRANE STIFFNESS LB/FT
      READ(NINP,9000)(RKVEC(I),I=1,NODES1)
C INPUT MEMBRANE DAMPING LB-SEC/FT
      READ(NINP,9000)(DAMP(I),I=1,NODES)
C
C CHANGE MASS TO SLUGS
      DO 5 I=1,NODES
      MASS(I)=MASS(I)/GO
5     CONTINUE
C
C SET EQUI SPACED ELEMENT LENGTHS
      DO 6 I=1,NODES1
      RLENGO(I)=LS/FLOAT(NODES1)
6     CONTINUE
C RLENGO SETTING OPTION
      READ(NINP,9015) IXF
C INPUT RLENGO IF IXF = 1
      IF(IXF.EQ.1) READ(NINP,9000)(RLENGO(I),I=1,NODES1)
C
C NORMALIZE SPRING CONSTANTS
      DO 7 I=1,NODES1
      RKVEC(I)=RKVEC(I)/RLENGO(I)
7     CONTINUE
C
C TRANSFORM DAMPING RATION INTO DAMPER VALUE
      DO 8 I=1,NODES
      DAMP(I)=2.0*SQRT(MASS(I)*RKVEC(I))*DAMP(I)
8     CONTINUE
C
```

```
C PRINT INITIAL VECTORS
      WRITE(NTYP,9053)
9053  FORMAT(5X,11H MASS NODES)
      CALL PUTMAT(MASS,NODES,NMATV,1)
      WRITE(NTYP,9054)
9054  FORMAT(5X,20H SPRING COEFFICIENTS )
      CALL PUTMAT(RKVEC,NODES1,NMATV,1)
      WRITE(NTYP,9055)
9055  FORMAT(5X,13H NODE DAMPING)
      CALL PUTMAT(DAMP,NODES,NMATV,1)
      WRITE(NTYP,9057)
9057  FORMAT(5X,9H LENGTH 0  )
      CALL PUTMAT(RLENG0,NODES1,NMATV,1)
C
C ************************************************************************
C
C SET BOUNDARY NODES
      X(1)=0.0
      Y(1)=0.0
      Y(NODES2)=-BX
      X(NODES2)=AX
C
C X,Y POINT OPTION
      READ(NINP,9015)IXY
      IF(IXY.EQ.1) GO TO 17
C
C INPUT NODE COORDINATES
C FOR INITIAL STIFFNESS CALCULATION
16    READ(NINP,9000)(X(I),I=2,NODES1)
      READ(NINP,9000)(Y(I),I=2,NODES1)
9000  FORMAT(8G10.5)
      GO TO 45
C
C COMPUTE TRUNK SHAPE
17    CALL TRUNK(ISHAPE)
      NX=IFIX(FLOAT(NODES)*(PHI2*R2/RL))
      NZ=NODES-NX
C
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```
C COMPUTE RIGHT SECTOR POINTS
      XCNTR=R2*SIN(PHI2)
      YCNTR=HY-R1
      TX=2.0*ASIN(RLENGO(1)*0.5/R1)
      ANG=ATAN2((X(NODES2)-XCNTR),(Y(NODES2)-YCNTR))
      DO 18 I=1,NZ
      ANG=ANG-TX
      J=NODES2-I
      X(J)=XCNTR+R1*SIN(ANG)
      Y(J)=YCNTR+R1*COS(ANG)
18    CONTINUE
C
C COMPUTE LEFT SECTOR POINTS
      YCNTR=YCNTR+R1-R2
      ANG=1.570796-PHI2
      TX=2.0*ASIN(RLENGO(1)*0.5/R2)
      DO 19 I=1,NX
      ANG=ANG+TX
      J=I+1
      X(J)=XCNTR-R2*COS(ANG)
      Y(J)=YCNTR+R2*SIN(ANG)
19    CONTINUE
C
C PRINT X,Y POSITIONS
45    WRITE(NTYP,9010)
9010  FORMAT(//,5X,15H NODE POSITIONS,/,2X,2H X,10X,2H Y ,/)
      DO 20 I=1,NODES2
      WRITE(NTYP,9020)  X(I),Y(I)
9020  FORMAT(2(2X,F8.4))
20    CONTINUE
      WRITE(NTYP,9001)
C
      DO 50 I=1,NODES1
C COMPUTE SPRING LENGTHS
      RLENG(I)=SQRT((X(I+1)-X(I))**2+(Y(I+1)-Y(I))**2)
C COMPUTE THETA ANGLES
      TX=ATAN2((Y(I+1)-Y(I)),(X(I+1)-X(I)))
      THETA(I)=TX
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```
      COSTHE(I)=COS(TX)
      SINTHE(I)=SIN(TX)
50    CONTINUE
C
C COMPUTE LOCAL SLOPE ANGLE,ALPHA
      DO 55 I=1,NODES
      TX=ATAN2((Y(I+2)-Y(I)),(X(I+2)-X(I)))
      SINALP(I)=SIN(TX)
      COSALP(I)=COS(TX)
55    CONTINUE
C
C ***********************************************************************
C
C CONTINUOUS STRING FREQUENCIES
C NOTE * ONLY GOOD FOR EQUAL SPACED NODES,ELSE USE STRING LATERAL FREQUE
C
      RMASST=0.0
      DO 70 I=1,NODES
      RMASST=RMASST+MASS(I)
70    CONTINUE
      WRITE(6,9052)
9052  FORMAT(/,5X,30H CONTINUOUS STRING FREQUENCIES ,3H HZ,/)
      DO 80 I=1,NODES
      W=FLOAT(I)*SQRT(TENSN*RL/RMASST)/(RL*2.0)
      WRITE(6,9050)W
80    CONTINUE
C
C ***********************************************************************
C
C 2 DIMENSIONAL UNDAMPED MATRIX MODEL
C
      IF(ICNTL(1).LE.0) GO TO 202
C
      IF(NODES.GT.NUMAX) GO TO 615
      CALL CLEAR(WORKM,NMAT,NMAT)
      CALL CLEAR(G,NMAT,NMAT)
      CALL CLEAR(XW,NMAT,NMAT)
      K=0
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C
      DO 2000 IJK=1,NODES1
C ADD DIRECT STIFFNESS SUBMATRIX INTO GLOBAL MATRIX G
C
      CALL ELEMK(ESTIF(1,1),THETA(IJK),-RKVEC(IJK))
C
      DO 100 I=1,4
      DO 100 J=1,4
      IK=I+K-2
      IF((IK.LT.1).OR.(IK.GT.NMAX)) GO TO 100
      JK=J+K-2
      IF((JK.LT.1).OR.(JK.GT.NMAX)) GO TO 100
      WORKM(IK,JK)=WORKM(IK,JK)+ESTIF(I,J)
100   CONTINUE
      K=K+2
2000   CONTINUE
C
C ADD TENSION SPRING EFFECT MODEL INTO STIFFNESS MATRIX
      DO 450 I=1,NODES
      J=(I-1)*2+1
      TX=TENSN*2.0/(RLENG(I)+RLENG(I+1))*SINALP(I)
      TY=TENSN*2.0/(RLENG(I)+RLENG(I+1))*COSALP(I)
C
      IF(I.EQ.1) GO TO 440
       G(J,J-2)=G(J,J-2)+TX*SINALP(I-1)
      G(J,J-1)=G(J,J-1)+TX*COSALP(I-1)
      G(J+1,J-2)=G(J+1,J-2)+TY*SINALP(I-1)
      G(J+1,J-1)=G(J+1,J-1)+TY*COSALP(I-1)
C
440   G(J,J)=G(J,J)+TX*SINALP(I)*(-2.0)
      G(J,J+1)=G(J,J+1)+TX*COSALP(I)*(-2.0)
      G(J+1,J)=G(J+1,J)+TY*SINALP(I)*(-2.0)
      G(J+1,J+1)=G(J+1,J+1)+TY*COSALP(I)*(-2.0)
C
      IF(I.EQ.NODES) GO TO 450
      G(J,J+2)=G(J,J+2)+TX*SINALP(I+1)
      G(J,J+3)=G(J,J+3)+TX*COSALP(I+1)
      G(J+1,J+2)=G(J+1,J+2)+TY*SINALP(I+1)
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```
      G(J+1,J+3)=G(J+1,J+3)+TY*COSALP(I+1)
450   CONTINUE
C
C SUM LONGITUDINAL AND LATERAL FORCE COMPONENTS
      DO 420 I=1,NMAX
      K=(I-1)/2+1
      DO 420 J=1,NMAX
      G(I,J)=(G(I,J)+WORKM(I,J))/MASS(K)
420   CONTINUE
      CALL MOVE(G,WORKM,NMAX,NMAT)
C
      WRITE(6,9101)
9101  FORMAT(/,20H 2D UNDAMPED MATRIX ,/)
      IF(IPRNT(1).EQ.1) CALL PUTMAT(G,NMAX,NMAT,NMAX)
C
C COMPUTE EIGENVALUES/EIGENVECTORS OF 2D MATRIX
      CALL EIGPAC(NMAX,NMAT,G,WORK1,WORK2,EVEC,+2,ICNTL(1),WORKM,XW)
C
C ************************************************************************
C
C 2 DIMENSIONAL DAMPED MEMBRANE MATRIX MODEL
C
202   IF(ICNTL(2).LE.0) GO TO 615
C
C A IS DAMPED 2*N STATE COEFFICIENT MATRIX
      IF(NODES.GT.NDMAX) GO TO 615
      CALL CLEAR(A,NMAT,NMAT)
      CALL CLEAR(AS,NMAT,NMAT)
      CALL CLEAR(AT,NMAT,NMAT)
      IO=1
      JO=1
C
C SET DAMPING AND PURE INTEGRATOR COEFFICIENTS
      DO 1010 I=1,NODES
      A(IO,JO)=-DAMP(I)
      A(IO+1,JO)=1.0
      A(IO+3,JO+2)=1.0
      A(IO+2,JO+2)=-DAMP(I)
```

```
      JO=JO+4
      IO=IO+4
 1010 CONTINUE
C
C ADD STIFFNESS TERMS FOR ALL SPRINGS
      DO 1020 I=1,NODES1
      IO=(I-1)*4-5
C
      CALL ELEMK(ESTIF(1,1),THETA(I),-RKVEC(I))
C
      DO 1030 J=1,4
      DO 1030 K=1,4
      L=(J*2)+IO
      IF((L.LT.1).OR.(L.GT.NMAX2)) GO TO 1030
      M=(K*2)+IO+1
      IF((M.LT.1).OR.(M.GT.NMAX2)) GO TO 1030
      A(L,M)=A(L,M)+ESTIF(J,K)
 1030 CONTINUE
 1020 CONTINUE
C
C ADD TENSION SPRING EFFECT MODEL INTO STIFFNESS MATRIX
       DO 1025 I=1,NODES
      J=(I-1)*4+1
      TX=TENSN*2.0/(RLENG(I)+RLENG(I+1))*SINALP(I)
      TY=TENSN*2.0/(RLENG(I)+RLENG(I+1))*COSALP(I)
C
      IF(I.EQ.1) GO TO 1022
      A(J,J-1)=A(J,J-1)+COSALP(I-1)*TY
      A(J,J-3)=A(J,J-3)+TX*SINALP(I-1)
      A(J+2,J-3)=A(J+2,J-3)+TX*SINALP(I-1)
      A(J+2,J-1)=A(J+2,J-1)+TY*COSALP(I-1)
 1022 A(J,J+1)=A(J,J+1)+TX*SINALP(I) *(-2.0)
      A(J,J+3)=A(J,J+3)+TY*COSALP(I)*(-2.0)
      A(J+2,J+1)=A(J+2,J+1)+TX*SINALP(I)*(-2.0)
      A(J+2,J+3)=A(J+2,J+3)+TY*COSALP(I)*(-2.0)
C
      IF(I.EQ.NODES) GO TO 1025
      A(J,J+5)=A(J,J+5)+TX*SINALP(I+1)
```

```
      A(J,J+7)=A(J,J+7)+TY*COSALP(I+1)
      A(J+2,J+5)=A(J+2,J+5)+TX*SINALP(I+1)
      A(J+2,J+7)=A(J+2,J+7)+TY*COSALP(I+1)
1025  CONTINUE
      DO 1040 I=1,NMAX2,2
      K=I/4+1
      DO 1040 J=1,NMAX2
      A(I,J)=A(I,J)/MASS(K)
1040  CONTINUE
      CALL MOVE(A,AS,NMAX2,NMAT)
C
      WRITE(6,9102)
9102  FORMAT(/,17H 2D DAMPED MATRIX   ,/)
      IF(IPRNT(2).EQ.1) CALL PUTMAT(A,NMAX2,NMAT,NMAX2)
C
C COMPUTE EIGENVALUES/EIGENVECTORS OF 2D MATRIX
      CALL EIGPAC(NMAX2,NMAT,A,WORK1,WORK2,EVEC,-2,ICNTL(2),AS,AT)
C
C *************************************************************************
C
C UNDAMPED LATERAL STRING MODEL
C
615   IF(ICNTL(3).LE.0) GO TO 700
C
C GS HOLDS STRING SYSTEM MATRIX
      IF(NODES.GT.(2*NUMAX)) GO TO 800
      CALL CLEAR(GS,NMAT,NMAT)
      CALL CLEAR(XZ,NMAT,NMAT)
      CALL CLEAR(XT,NMAT,NMAT)
      NODEM1=NODES-1
C
      DO 630 I=2,NODEM1
C COMPUTE MEMBRANE TENSION
      TX=TENSN/MASS(I)/RLENGO(I)
      GS(I,I)=-2.0*TX
      GS(I,I+1)=TX
      GS(I,I-1)=TX
630   CONTINUE
```

```
C SET FIRST AND LAST BOUNDARY ELEMENTS
      TX=TENSN/MASS(1)/RLENGO(1)
      GS(1,1)=-2.0*TX
      GS(1,2)=TX
      TX=TENSN/MASS(NODES)/RLENGO(NODES)
      GS(NODES,NODES)=-2.0*TX
      GS(NODES,NODEM1)=TX
      CALL MOVE(GS,XZ,NODES,NMAT)
C
      WRITE(6,9103)
9103  FORMAT(/,15H LATERAL STRING  ,/)
      IF(IPRNT(3).EQ.1) CALL PUTMAT(GS,NODES,NMAT,NODES)
C
C COMPUTE EIGENVALUES/EIGENVECTORS OF 2D MATRIX
      CALL EIGPAC(NODES,NMAT,GS,WORK1,WORK2,EVEC,+1,ICNTL(3),XZ,AT)
C
C ************************************************************************
C
C DAMPED LATERAL STRING MODEL
C
700   IF(ICNTL(4).LE.0) GO TO 800
C
C XW HOLDS DAMPED STRING SYSTEM A MATRIX
      IF(NODES.GT.(2*NDMAX)) GO TO 800
      CALL CLEAR(XW,NMAT,NMAT)
      CALL CLEAR(G,NMAT,NMAT)
      CALL CLEAR(WORKM,NMAT,NMAT)
C
C SET PURE INTEGRATOR ELEMENTS
      DO 710 I=1,NODES
      J=I*2
      K=I*2-1
      XW(J,K)=1.0
710   CONTINUE
C
C LOAD TENSILE TERMS
      NODEM1=NODES-1
      DO 720 I=2,NODEM1
```

```
      TX=TENSN/MASS(I)/RLENGD(I)
       J=I*2-1
      XW(J,J)=-DAMP(I)/MASS(I)
      XW(J,J-1)=TX
      XW(J,J+3)=TX
      XW(J,J+1)=-2.0*TX
720   CONTINUE
C
C SET FIRST AND LAST BOUNDARY ELEMENTS
      TX=TENSN/MASS(1)/RLENGD(1)
      XW(1,1)=-DAMP(1)/MASS(1)
      XW(1,2)=-2.0*TX
      XW(1,4)=TX
      TX=TENSN/MASS(NODES)/RLENGD(NODES)
      J=NODES*2-1
      XW(J,J)=-DAMP(NODES)/MASS(NODES)
      XW(J,J-1)=TX
      XW(J,J+1)=-2.0*TX
      NODET2=NMAX
      CALL MOVE(XW,G,NMAX,NMAT)
C
      WRITE(6,9104)
9104  FORMAT(/,22H LATERAL DAMPED STRING  ,/)
      IF(IPRNT(4).EQ.1) CALL PUTMAT(XW,NMAX,NMAT,NMAX)
C
C COMPUTE EIGENVALUES/EIGENVECTORS OF 2D MATRIX
      CALL EIGPAC(NMAX,NMAT,XW,WORK1,WORK2,EVEC,-1,ICNTL(4),G,WORKM)
C
C ************************************************************************
C
C UNDAMPED LONGITUDINAL BAR MODEL
C
800   IF(ICNTL(5).LE.0) GO TO 850
C
C GS IS UNDAMPED MODEL
C
      IF(NODES.GT.(2*NUMAX)) GO TO 800
      CALL CLEAR(GS,NMAT,NMAT)
```

```
      CALL CLEAR(XZ,NMAT,NMAT)
      CALL CLEAR(XT,NMAT,NMAT)
      NODEM1=NODES-1
C
C SET UP STIFFNESS MATRIX
      DO 820 I=2,NODEM1
      GS(I,I)=-RKVEC(I)-RKVEC(I+1)
      GS(I,I-1)=RKVEC(I)
      GS(I,I+1)=RKVEC(I+1)
820   CONTINUE
C SET FIRST AND LAST BOUNDARY NODES
      GS(1,1)=-RKVEC(1)-RKVEC(2)
      GS(1,2)=RKVEC(2)
      GS(NODES,NODES)=-RKVEC(NODES)-RKVEC(NODES1)
      GS(NODES,NODEM1)=RKVEC(NODES)
C
      DO 830 I=1,NODES
      DO 830 J=1,NODES
      GS(I,J)=GS(I,J)/MASS(I)
830   CONTINUE
      CALL MOVE(GS,XZ,NODES,NMAT)
C
      WRITE(6,9105)
9105  FORMAT(/,20H LONGITUDINAL STRING   ,/)
      IF(IPRNT(5).EQ.1) CALL PUTMAT(GS,NODES,NMAT,NODES)
C
C COMPUTE EIGENVALUES/EIGENVECTORS OF 2D MATRIX
      CALL EIGPAC(NODES,NMAT,GS,WORK1,WORK2,EVEC,+1,ICNTL(5),XZ,XT)
C
C *****************************************************************************
C
C DAMPED LONGITUDINAL BAR MODEL
C
850   IF(ICNTL(6).LE.0) GO TO 900
C
      IF(NODES.GT.(2*NDMAX)) GO TO 900
      CALL CLEAR(G,NMAT,NMAT)
      CALL CLEAR(WORKM,NMAT,NMAT)
```

```
      CALL CLEAR(XW,NMAT,NMAT)
C
C SET PURE INTEGRATOR ELEMENTS
      DO 860 I=1,NODES
      J=I*2
      K=I*2-1
      XW(J,K)=1.0
860   CONTINUE
      NODEM1=NODES-1
C
C SET UP DAMPED STIFFNESS MATRIX
      DO 870 I=2,NODEM1
      J=I*2-1
      XW(J,J)=-DAMP(I)
      XW(J,J-1)=RKVEC(I)
      XW(J,J+3)=RKVEC(I+2)
      XW(J,J+1)=-RKVEC(I+1)-RKVEC(I)
870   CONTINUE
C SET FIRST AND LAST BOUNDARY ELEMENTS
      XW(1,1)=-DAMP(1)
      XW(1,2)=-RKVEC(1)-RKVEC(2)
      XW(1,4)=RKVEC(2)
      J=NODES*2-1
      XW(J,J)=-DAMP(NODES)
      XW(J,J-1)=RKVEC(NODES)
      XW(J,J+1)=-RKVEC(NODES)-RKVEC(NODES+1)
C
      DO 880 I=1,NMAX,2
      DO 880 J=1,NMAX
      K=I/2+1
      XW(I,J)=XW(I,J)/MASS(K)
880   CONTINUE
      CALL MOVE(XW,G,NMAX,NMAT)
C
      WRITE(6,9106)
9106  FORMAT(/,27H LONGITUDINAL DAMPED STRING  ,/)
      IF(IPRNT(6).EQ.1) CALL PUTMAT(XW,NMAX,NMAT,NMAX)
C
```

```
C COMPUTE EIGENVALUES/EIGENVECTORS OF 2D MATRIX
      CALL EIGPAC(NMAX,NMAT,XW,WORK1,WORK2,EVEC,-1,ICNTL(6),G,WORKM)
C
C ***********************************************************************
C
900   CALL EXIT
      END
```

```
      SUBROUTINE TRUNK(ISHAPE)
C TRUNK GEOMETRY CALCULATIONS
C
      REAL L,L1,L2,LS,LP,MASS
      COMMON/GEOMET/A,B,HY,L,L1,L2,R1,R2,PHI1,PHI2
      DATA RTOL/0.01/
C
      IF(HY.LE.0.0) GO TO 11
C***********************************************************************
C ITERATION FOR R2
C COMPUTE INNER RADIUS OF CURVATURE
      R2=SQRT(A*A*0.25+HY*HY)
C
C ITERATION LOOP FOR L2,L1,R1,R2
        DO 10 I=1,50
      PHI2=ABS(ACOS(AMAX1(-1.0,AMIN1(1.0,((R2-HY)/R2)))))
       SINPH2=SIN(PHI2)
C COMPUTE OUTER RADIUS OF CURVATURE
      R1=((A-R2*SINPH2)**2+(B+HY)**2)/(2.*(B+HY))
      PHI1=ABS(ACOS(AMAX1(-1.0,AMIN1(1.0,((R1-HY-B)/R1)))))
       XS=A-R2*SINPH2
       IF (XS.LE.0.0) PHI1=6.2831852-PHI1
       L2=L-PHI1*R1
C R2S IS RESULTANT RADIUS FOR COMPUTED L2 IN ITERATION
      IF(ABS(PHI2) .LT.1.0E-2) PHI2=1.0E-2
       R2S=L2/PHI2
C TEST IF TOLERANCE .GT. ERROR
       IF(ABS(R2-R2S).LE.RTOL) GO TO 50
      R2=(R2+R2S)*0.5
10     CONTINUE
C***********************************************************************
C ITERATED 50 TIMES WITHOUT SUCCESS,ERROR RETURN
11    CONTINUE
       WRITE(6,9001)
9001    FORMAT(10X,26H INFEASIBLE TRUNK GEOMETRY ,//)
      ISHAPE=0
      RETURN
C TRUNK OK,RETURN
```

```
50     L1=L-L2
       TSHAPE=1
       RETURN
       END
```

```
      SUBROUTINE MOVE(A,AS,N,M)
C GENERAL MATRIX MOVE ROUTINE
      DIMENSION A(M,M),AS(M,M)
      DO 10 I=1,N
      DO 10 J=1,N
      AS(I,J)=A(I,J)
10    CONTINUE
      RETURN
      END
```

```
      SUBROUTINE CMINV(A,N,D,L,M)
C COMPLEX MATRIX INVERSION
C
      COMPLEX A,D,BIGA,HOLD
      DIMENSION A(1),L(1),M(1)
C
       NM=N*N
      D=CMPLX(1.0,0.0)
      NK=-N
      DO 80 K=1,N
      NK=NK+N
      L(K)=K
      M(K)=K
      KK=NK+K
      BIGA=A(KK)
      DO 20 J=K,N
      IZ=N*(J-1)
      DO 20 I=K,N
      IJ=IZ+I
10    IF(CABS(BIGA)-CABS(A(IJ))) 15,20,20
   15 BIGA=A(IJ)
      L(K)=I
      M(K)=J
   20 CONTINUE
C
C        INTERCHANGE ROWS
C
      J=L(K)
      IF(J-K) 35,35,25
   25 KI=K-N
      DO 30 I=1,N
      KI=KI+N
      HOLD=-A(KI)
      JI=KI-K+J
      A(KI)=A(JI)
   30 A(JI) =HOLD
C
C        INTERCHANGE COLUMNS
```

```
C
   35 I=M(K)
      IF(I-K) 45,45,38
   38 JP=N*(I-1)
      DO 40 J=1,N
      JK=NK+J
      JI=JP+J
      HOLD=-A(JK)
      A(JK)=A(JI)
   40 A(JI) =HOLD
C
C        DIVIDE COLUMN BY MINUS PIVOT (VALUE OF PIVOT ELEMENT IS
C        CONTAINED IN BIGA)
C
   45 IF(BIGA) 48,46,48
46    D=CMPLX(0.0,0.0)
      RETURN
   48 DO 55 I=1,N
      IF(I-K) 50,55,50
   50 IK=NK+I
      A(IK)=A(IK)/(-BIGA)
   55 CONTINUE
C
C        REDUCE MATRIX
C
      DO 65 I=1,N
      IK=NK+I
      HOLD=A(IK)
      IJ=I-N
      DO 65 J=1,N
      IJ=IJ+N
      IF(I-K) 60,65,60
   60 IF(J-K) 62,65,62
   62 KJ=IJ-I+K
      A(IJ)=HOLD*A(KJ)+A(IJ)
   65 CONTINUE
C
C        DIVIDE ROW BY PIVOT
```

```
C
      KJ=K-N
      DO 75 J=1,N
      KJ=KJ+N
      IF(J-K) 70,75,70
   70 A(KJ)=A(KJ)/BIGA
   75 CONTINUE
C
C        PRODUCT OF PIVOTS
      D=D*BIGA
C
C        REPLACE PIVOT BY RECIPROCAL
C
      A(KK)=CMPLX(1.0,0.0)/BIGA
   80 CONTINUE
C
C        FINAL ROW AND COLUMN INTERCHANGE
C
      K=N
  100 K=(K-1)
      IF(K) 150,150,105
  105 I=L(K)
      IF(I-K) 120,120,108
  108 JQ=N*(K-1)
      JR=N*(I-1)
      DO 110 J=1,N
      JK=JQ+J
      HOLD=A(JK)
      JI=JR+J
      A(JK)=-A(JI)
  110 A(JI) =HOLD
  120 J=M(K)
      IF(J-K) 100,100,125
  125 KI=K-N
      DO 130 I=1,N
      KI=KI+N
      HOLD=A(KI)
      JI=KI-K+J
```

```
      A(KI)=-A(JI)
  130 A(JI) =HOLD
      GO TO 100
  150 K=0
      RETURN
      END
```

```
      SUBROUTINE ELEMK(X,A,STIF)
C ELEMENT STIFFNESS MATRIX FORMULATION (2D)
C A IS LOCAL ROTATION ANGLE
      DIMENSION X(4,4)
C
C COMPUTE TRANSCENDENTALS ONCE
      CA=COS(A)
      SA=SIN(A)
      CASA=CA*SA
      SSA=SA*SA
      CSA=CA*CA
C
C ROTATION MATRIX
      X(1,1)=CSA
      X(1,2)=CASA
      X(1,3)=-CSA
      X(1,4)=-CASA
      X(2,1)=CASA
      X(2,2)=SSA
      X(2,3)=-CASA
      X(2,4)=-SSA
      X(3,1)=-CSA
      X(3,2)=-CASA
      X(3,3)=CSA
      X(3,4)=CASA
      X(4,1)=-CASA
      X(4,2)=-SSA
      X(4,3)=CASA
      X(4,4)=SSA
C
C MULTIPLY ROTATION MATRIX BY STIFFNESS
      DO 10 I=1,4
      DO 10 J=1,4
      X(I,J)=X(I,J)*STIF
10    CONTINUE
C
      RETURN
      END
```

```
      SUBROUTINE CLEAR(A,N,M)
C GENERAL MATRIX CLEAR TO ZERO
      DIMENSION A(1)
      NM=M*M
      DO 100 I=1,NM
      A(I)=0.0
100   CONTINUE
      RETURN
      END
```

```
      SUBROUTINE PUTMAT(A,N,M,L)
C MATRIX AND VECTOR PRINT OUT
      DIMENSION A(M,M)
      IF(L-1) 100,20,50
20    WRITE(6,9002)(A(I,1),I=1,N)
      WRITE(6,9001)
      GO TO 100
50    DO 75 I=1,N
      WRITE(6,9002)(A(I,J),J=1,L)
      WRITE(6,9001)
75    CONTINUE
100   CONTINUE
9001  FORMAT(/)
9002  FORMAT(5X,10G12.5)
      RETURN
      END
```

```
      SUBROUTINE PUTEIG(X,Y,N,IJK)
C EIGENVALUE OUTPUT ROUTINE
      DIMENSION X(1),Y(1)
C
      WRITE(6,9005)
9005  FORMAT(/,19H FREQUENCY OF MODES )
      IF(IJK) 2,1,1
C ONE DIMENSIONAL CASE
1     WRITE(6,9011)
9011  FORMAT(/,5X,45H       HZ              RAD/SEC              REAL   ,/)
      GO TO 3
2     WRITE(6,9010)
9010  FORMAT(/,5X,68H       HZ              RAD/SEC              REAL
     1     IMAG                 ,/)
3     DO 50 I=1,N
      IF(ABS(X(I)).LE.1.0E-05) X(I)=0.0
      IF(ABS(Y(I)).LE.1.0E-05) Y(I)=0.0
50    CONTINUE
C
      DO 100 I=1,N
C W=SQRT(RE**2+IM**2)
      W=SQRT(X(I)**2+Y(I)**2)
C IF NO DAMPING TAKE SORT
      IF(IJK.GT.0.0) W=SQRT(W)
C CONVERT TO HERTZ
      Z=W*0.15915494
      IF(IJK) 70,60,60
60    WRITE(6,9000) Z,W,X(I)
      GO TO 100
70    WRITE(6,9000) Z,W,X(I),Y(I)
9000  FORMAT(5(5X,G12.5))
100   CONTINUE
      RETURN
      END
```

```
      SUBROUTINE EIGPAC(N,M,A,WORK1,WORK2,EVEC,IJK,IFLAG,B,C)
C ROUTINE TO CALL SSP ROUTINES FOR EIGENVALUES
C N IS ARRAY SIZE TO DO , M IS STORAGE SIZE
C A,B CONTAIN SAME MATRIX
C WORK1,WORK2,C ARE WORK AREAS
      INTEGER EVEC
      DIMENSION A(1),WORK1(1),WORK2(1),EVEC(1)
      DIMENSION B(1),C(1)
C
C FORM HESSENBURG UPPER ALMOST TRIANGULAR MATRIX
20    CALL HSBG(N,A,M)
C
C COMPUTE EIGENVALUES WITH QR ALGORITHM
      CALL ATEIG(N,A,WORK1,WORK2,EVEC,M)
C
      CALL PUTEIG(WORK1,WORK2,N,IJK)
      IF(IABS(IFLAG)-2) 100,25,100
C CALL EIGENVECTOR ROUTINE IF NEEDED
25    CALL VECPAC(N,M,B,WORK1,WORK2,A,C)
100   RETURN
      END
```

```
      SUBROUTINE EVECTR(A,VEC,X,Y,N,M)
C ROUTINE TO COMPUTE EIGENVECTORS
C SOLVES FOR COMPLEX EIGENVECTORS OF A REAL MATRIX
C A,WORK,MAT ARE ALL FUNCTIONS OF VECPAC ARRAY SIZE
      COMPLEX X(M),Y(M),VEC(M)
      COMPLEX A(40,40)
      COMPLEX WORK(40)
      COMPLEX MAT(1600),DET
C
      IF(N.LE.1) RETURN
9001  FORMAT(5X,5(2G12.5))
      VEC(N)=CMPLX(1.0,0.0)
      NM1=N-1
      DO 100 I=1,NM1
      DO 100 J=1,NM1
      K=(J-1)*NM1+I
      MAT(K)=A(I,J)
100   CONTINUE
      IF(NM1-1) 200,200,300
200   MAT(1)=CMPLX(1.0,0.0)/MAT(1)
      GO TO 400
C
C MATRIX INVERSION
300   CALL CMINV(MAT,NM1,DET,X,Y)
      IF(DET.EQ.CMPLX(0.0,0.0)) WRITE(6,9000)
9000  FORMAT(5X,17H DETERMINANT ZERO    )
C
400   DO 500 I=1,NM1
      VEC(I)=CMPLX(0.0,0.0)
      DO 500 J=1,NM1
      K=(J-1)*NM1+I
      VEC(I)=VEC(I)-A(J,N)*MAT(K)
500   CONTINUE
      RETURN
      END
```

```
      SUBROUTINE VECPAC(N,M,A,EIGR,EIGI,X,Y)
C EIGENVECTOR COMPUTATION/OUTPUT CONTROL ROUTINE
C N IS NUMBER OF NODES,M IS DIMENSION
C NOTE * AC MUST BE DIMENSIONED TO (M*M)
C NOTE * X,Y MUST BE DIMENSIONED TO (M*2)
      COMPLEX X(81),Y(81)
      COMPLEX AC(40,40)
      DIMENSION A(M,M),EIGR(M),EIGI(M)
C
      NTYP=6
C SOLVE FOR EACH VECTOR
      DO 1000 K=1,N
      IF(K.EQ.1) GO TO 3
C SKIP SECOND HALF OF COMPLEX CONGUGATE PAIR
      IF((EIGR(K).EQ.EIGR(K-1)).AND.(EIGI(K).EQ.-EIGI(K-1)))GO TO 1000
3     CONTINUE
C LOAD EIGENVECTORS INTO COMPLEX VECTOR
      DO 5 I=1,N
      X(I)=CMPLX(EIGR(I),EIGI(I))
5     CONTINUE
C FORM COMPLEX MATRIX FROM REAL A
      DO 10 I=1,N
      DO 10 J=1,N
      AC(I,J)=CMPLX(A(I,J),0.0)
10    CONTINUE
C
C SUBTRACT EIGENVALUE FROM DIAGONAL OF A MATRIX
       DO 100 I=1,N
      AC(I,I)=AC(I,I)-X(K)
100   CONTINUE
C
C CALL EIGENVECTOR SOLVER
      CALL EVECTR(AC,Y,X(N+1),Y(N+1),N,M)
C
      WRITE(NTYP,9000) X(K),Y(1)
      WRITE(NTYP,9001)(Y(J),J=2,N)
9000  FORMAT(//,5X,11H EIGENVALUE ,2X,2F15.5,//,5X,14H EIGENVECTOR
     1,2F15.5)
```

```
9001   FORMAT(19X,2F15.5)
C NORMALIZE REAL PARTS OF DISPLACEMENT EIGENVECTORS
       XMAX=0.0
       DO 200 I=2,N,2
       IF(ABS(REAL(Y(I))).LT.XMAX) GO TO 200
       XMAX=REAL(Y(I))
200    CONTINUE
       WRITE(6,9010)
9010   FORMAT(/,42H REAL DISPLACEMENT NORMALIZED EIGENVECTORS   ,/)
       DO 300 I=2,N,2
       XT=REAL(Y(I))/XMAX
       WRITE(6,9001)XT
300    CONTINUE
1000   CONTINUE
       RETURN
       END
```


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